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COMPRESSED AIR

Its Production, Uses, and Applications

COMPRISING

THE PHYSICAL PROPERTIES OF AIR FROM A VACUUM
TO ITS LIQUID STATE, ITS THERMODYNAMICS,
COMPRESSION, TRANSMISSION AND USES

AS A

MOTIVE POWER

In the Operation of Stationary and Portable Machinery, in Mining, Air Tools,
Air Lifts, Pumping of Water, Acids, and Oils; the Air Blast for Cleaning
and Painting, the Sand Blast and its Work, and the Numerous
Appliances in which Compressed Air is a Most Con-
venient and Economical Transmitter of Power for
Mechanical Work, Railway Propulsion, Re-
frigeration and the Various Uses
to which Compressed
Air has been
Applied.

WITH FORTY AIR TABLES AND FIVE HUNDRED AND FORTY-FIVE ILLUSTRATIONS

By GARDNER D. HISCOX, M.E.

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Oil Engines," "Horseless Vehicles, Automobiles," etc., etc.

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PREFACE.

THE literature on the commercial uses of compressed air, especially in its application to the mechanic arts, has not kept pace with the growing importance of the subject, having been confined, in the main, to occasional papers presented to engineering societies, and to special articles appearing at intervals in the various technical journals of this and foreign countries, or in the still more fugitive form of trade circulars; but even these, fragmentary publications at best, cover scarcely more than the past two decades.

The thermodynamic treatment of air under compression, its transmission and expansion, have been ably worked out by careful experimenters and communicated to scientific societies by competent writers; these articles, valuable in themselves, have not met the requirements of the modern engineer, whose immediate necessities demand a more complete gathering of the widely distributed data relating to this subject, as well as a better classification of the known properties of the atmosphere. This want has long been apparent to the author by reason of many years' experience in answering constantly recurring inquiries relating to compressed air, and to its direct application to the commercial needs of the day. The fund of information acquired and carefully preserved by the author during the many years of his editorial work is now brought into compact form and in a single volume for ready reference. That this has been no light task will be apparent from even a casual perusal of the present work.

The progressive advancement in experimental research ex-

tends in two opposite directions: the partial vacuum incident to the ordinary operations of an air pump or the condensation of watery vapor has been extended by other methods to the highly attenuated results obtained in the manufacture of incandescent lamps; while, on the other hand, compression has extended through its various stages until, and in connection with a very low temperature, the final product, liquid air, has been made commercially available. Many of the difficulties in regard to the expression of mathematical details and thermodynamic formulas have arisen in consequence of this progressive advancement; so also, the knowledge of the atmospheric relation to other elements is yet in a progressive state; the practical application of compressed air for doing mechanical work is of so recent date that the design and construction of any of the most useful machines operated by compressed air rest upon empirical rather than scientific formulas. It is one of the objects of the present volume to make available the ascertained facts of experimental research in atmospheric phenomena, and, so far as possible, the fundamental basis upon which such ascertained facts securely rest.

To limit the consideration of the properties of air when simply compressed above the ordinary pressure of the atmosphere was believed to be wanting in scope to make the treatment of the subject complete; this work includes, therefore, a consideration of the properties of air below atmospheric pressure, for the reason that we are surrounded by an atmosphere compressed by gravity, but it is used in the arts in many ways much below atmospheric pressure, even approaching the zero condition of a vacuum, so that, remote as the connection appears, this subject of partial pressures below the atmosphere properly belongs to a treatise on compressed air.

The wide range of manufacturing interests in which compressed air plays an important or even a subordinate part is such that special machines for its production and utilization are as numerous as the diversified industries of our day; this

condition has suggested the large number of illustrations employed to place before the reader the salient features of only the latest and best designs. These designs include portable machines, together with a large number of individual and special tools designed for and greatly contributing to the lessening of manual labor, as well as tending to increase the output of useful work.

The development of the caisson method in submarine work for engineering structures has become very general; requiring not only special appliances, but introducing problems in hygiene which do not ordinarily occur in engineering practice; the sensations and physical effect of varying air pressures and temperatures upon workmen engaged in labor of this kind belong essentially to the subject-matter of this work, and have been included.

Within the past few years an important and useful commercial effect has been obtained by the use of compressed air and its subsequent expansion in the production of temperatures suited to refrigerating purposes; such machines are in use on warships and other vessels in which, for one reason or another, the use of ammonia gas is either objectionable or prohibitive.

The author, recognizing the economic value of such machines, has given considerable space to the consideration of the physical and thermodynamic problems connected therewith. There are many interesting problems in this connection which lie beyond the domain of commercial refrigeration, in which, by the production of temperatures far below the Fahrenheit zero and approaching the absolute zero, the critical temperature of air is passed and its physical condition changed from a gaseous to a liquid, and thence to a solid state; as this subject has been fully treated in a recent volume on *Liquid Air*, it has therefore been given but limited space in this work.

Among the available sources of information employed by the writer have been the various standard treatises on thermodynamics, including Weisbach, Rankine, Roentgen and Dubois,

Thurston, De Volson, Wood, and others; free use has been made of articles on compressed air and its appliances which have appeared in the *Scientific American* from time to time; acknowledgment is also due to the leading technical journals of this country and of Europe; while the writer would be wanting in appreciation and gratitude if he failed to suitably acknowledge the action of his friend Mr. William L. Saunders, editor and proprietor of the journal *Compressed Air*, who, with characteristic liberality, tendered the entire valuable contents and illustrations of this journal to the use of the author in the preparation of this volume.

GARDNER D. HISCOX.

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Chapter I.

HISTORICAL

HISTORICAL.

THE use of air in its lower condition of compression for power and for mechanical purposes has been known from the earliest ages, and antedates any knowledge we possess of the use of steam by many generations.

The reduction of metals from their ores and the forging of iron and steel brought the forge and the blast furnace, with the use of air under pressure, into existence as mechanical appliances more than two thousand years before the Christian Era.

The evidences of the use of the air blast under compression are plainly seen depicted on the sculptured walls of the structures of the oldest civilization, and are made still more manifest in its endurated paintings and in the legends of the early historians.

The first inception of air power, as gathered from the example of the winds, seems to have been less progressive in its uses than other of the mechanical arts; for, while it formed one of the vital elements in producing the metals, the inventive instinct in handicraft seems also to have been instilled in the early workers of metals in creating the tools that by the ancient genius of art worked out the models of beauty that are our examples of to-day.

The old methods of compressed-air production seem to have taken on a crude and nearly stationary form for at least two thousand years before, and for more than a thousand years after, the Christian Era, and in some parts of the world may be seen in operation to this day.

In China, India, Burmah, Borneo, Africa, and Madagascar the primitive methods of compressing air are still in use: the

air treading bags, the wooden cylinder and piston, and the Chinese wind-box are the common devices for producing the air blast.

The only further progress that appears on record in regard to the production of compressed air and its uses for power purposes has been handed down in fragmentary history, and mostly contained in the pneumatics of Heron of Alexandria.

From the descriptions extant, he seems to have been the first to invent or to describe the pressure air pump or compressor for pressures greater than the forge blast, and to have applied it in the famous fountain attributed to him. Notwithstanding the alleged ignorance of the ancients respecting the physical properties of the atmosphere, there are circumstances related in history which seem to indicate the reverse; for Diogenes of Apollonia reasoned on its condensation and rarefaction.

The description of the fire engine of the Egyptians, as given in Heron's "Spiritalia," shows very plainly that the use of air compression and its elasticity in the air chamber of a hydraulic pump were well understood in the second century before the Christian Era.

The devices of the Egyptian priesthood for exciting the wonder and awe of the people, possessed as they were of the superstitions and proclivities of that age, were no doubt derived from a general knowledge of many of the physical laws of the elements possessed by the ruling and priestly classes.

They understood the nature of the expansion and contraction of air by heat and cold, of which the vocal statue on the plain of Thebes was an example.

The movement of the statue of Serapis and the altar tricks of the Pharaonic priesthood are other examples of the designed antics, due to the use of compressed air and the vapor of water.

Had it not been for the written work of Heron, the "Spiritalia," we should never have suspected that *air* was made to

perform so important a part in ancient frauds, nor that its compression and expansion had been employed to raise liquids.

Notwithstanding the high opinion which history gives us of the historical and philosophical knowledge of the old Egyptian priesthood, we should hardly have surmised that they had the art of applying this subtle fluid so ingeniously. They seem, however, to have searched all nature for devices; and to have become familiar with many of the principles upon which the most valuable of our arts and mechanics are based.

The condensing air pump or compressor must have been used in charging the *wind guns* of Ctesibius of Alexandria, about 120 B.C., as described by Vitruvius. The properties exhibited by a partial vacuum must have been well known from five hundred to one thousand years before the Christian Era, as illustrated in the use of the siphon and the atmospheric watering-pots of the early Egyptians, though the principle of the perfect vacuum is undoubtedly due to Torricelli, by his production of the mercurial vacuum, about 1643 A.D.

The air-pressure bellows, in its many forms, seems to have been confined to a stated use, that of forcing a fire, from the earliest times, when a slight advance was made in air pressure to operate the devices and toys used in priestly incantations, followed by its application in the propulsion of projectiles by Ctesibius.

Then its principles slumbered in its low-pressure use for more than a thousand years, when the arrow discharged under air pressure by Ctesibius finally developed into the pneumatic gun of Marin in France, which was presented to Henry IV. in 1600. A more perfect compressed-air gun was brought out by Guter at Nuremberg in 1656, which had attached to the stock, in musket form, all the appliances for charging and discharging by air compression. But little further progress was made in this line until near the middle of the nineteenth century, when compressed-air guns took a wide range of design; their most

useful and effective outcome being the pneumatic guns of Zalinski and others.

While the mechanic arts slumbered through the dark ages in Europe, the Chinese seem to have improved the aboriginal piston blower by a more perfect action and finish, in an instrument styled by them the "wind-box."

The water trombe, or tromp, for compressing air by a fall of water in a tube, used for blowing forges and other purposes, was known to Heron, and was mentioned by Pliny in his "Natural History."

In improved form the tromp has held its place for two thousand years, and is in use at the present day in Europe and the Orient.

The principle of Heron's pneumatic fountain for raising water was carried out on a large and useful scale in the pneumatic pumping engine at the mines of Chemnitz, in Hungary, erected by M. Hoell in 1755; there was probably first illustrated the refrigerating power of air when expanded from great pressure. In the lower chamber of this apparatus the discharge of air and its expansion with water produced hail or pellets of ice. At first this machine required personal attention in its manipulation, but in 1796 it was made automatic.

The use of compressed air for submarine work was no doubt well known in the earliest ages, being almost coeval with the dawn of commerce.

Aristotle (350 B.C.) describes a kettle in which divers supplied themselves with fresh air under water. The legend of the descension of Alexander the Great to the bottom of the sea in a vessel called a *colympia*, with a glass window in it, is no doubt an allusion to the use of the diving-bell. It was employed in Phœnicia in the year 320 B.C., and the use of glass was well known then.

Nothing further appears on record in regard to submarine work with a bell for more than fifteen hundred years, when mention of its use in Spain in 1538 is met with. Bacon de-

scribes it (1620) as a machine used to assist persons laboring under water upon wrecks, affording a reservoir of air into which they could enter to take breath.

From this time on for a hundred years the diving-bell was largely used in Europe in recovering wreckage and treasure; in 1715 Dr. Halley made the first contrivance for supplying the diving-bell with fresh air by lowering air-filled barrels and discharging the air under the bell, letting out the foul air at the top through a cock; or of allowing of completely filling the space with air that was made unavailable heretofore by the compression of the air in the bell.

Dr. Halley suggested the present system of submarine armor by using a cap or portable helmet connected with a tube leading to the surface, through which fresh air was forced to the helmet for the needs of the diver. Smeaton and Brunel, from 1779 on, improved on the use of the diving-bell, making its operation continuous by a fresh supply of compressed air through tubes from pumps.

The submarine armor continued to be improved along the lines of its present form for deep-sea work, in which depths of 148 feet have been attained, involving work under an air pressure of 65 pounds per square inch for several hours. It has been claimed that a depth of 200 feet has been reached without serious results from the great pressure due to that depth.

The compressed-air and vacuum pump was greatly improved by Otto Van Guericke about 1650, and it has been claimed as his invention.

Savary increased the pressure of air for blast furnaces by the use of more substantial blowers, in the latter part of the seventeenth century.

Denys Papin was the first to propose and make, in 1653, an actual trial of the transmission of power to a distance by compressed air. His early ideas being finally developed into more practicable shape, they resulted in his recommending the

use of water power for compressing air and forcing it to a distance for useful work, thus foreshadowing the now common practice of the long transmission and distribution of air through mines for the operation of machinery.

His system of an air pump driven by a water wheel, operating on air and water chambers at a distance, was in the right direction, but failed in its practical operation by the elasticity of the air, which he had intended to use as a long piston in transmitting power from an air-working piston to a distant water piston.

It was the fertile and mechanical brain of Papin that first conceived the idea of the pneumatic tube for transmitting parcels by air pressure, thus antedating by more than two hundred years our pneumatic-tube postal and package service, and thus early opening the way for future advancement in the use of compressed air.

Experiments were made in Wales in these early years to utilize water power for compressing air and transmitting it long distances for operating blast furnaces.

In 1757, Wilkinson, in England, patented a method of compressing air by the use of a column of water, effecting his object by means of a series of chambers or water compressors, used one after another, so as to keep up a regular pressure; thus, in a crude way, preceding by a hundred years the water compressor of Sommeiller at the Mont Cenis tunnel.

Many vague descriptions of apparatus for the use of compressed air in the mechanic arts and for its compression are found in the English patents during the eighteenth century; but either their practical applications were never realized or else no record was made of their operation.

The application of compressed air to practical uses and its transmission for power purposes seem to have commenced an era of advancement in the last years of the eighteenth century.

Professor St. Clair, of the Edinburgh University, in 1785, proposed attaching air bags to sunken vessels beneath the

surface of the water and inflating them by air pumps; followed by its practical use for raising vessels, for which many patents have been issued in Europe and the United States for various modifications of this device. Its most successful trials were made in 1864 in raising a steamer sunk in Lake Boden, and in raising the vessels sunk at Sebastopol during the Crimean War.

From that time on many patents have been issued for various devices for raising vessels by inflating floats by air pressure, and for compressing air and its use in diving-bells and submarine armor.

Medhurst, a Danish engineer in England, in 1799 compressed air to 15 atmospheres (210 pounds), stored and transmitted it to a motor in a mine; he patented a pneumatic system for conveying persons and parcels in tubes in 1810, followed by publications during a period of several years on tubular transmission by compressed air. There is no record of the practical working of the many schemes of this fertile genius.

Compressed air for driving vehicles seems to have had its birth with the beginning of the nineteenth century in a patent to Medhurst, in England, August 2, 1800, for means for propelling carriages by compressed air from a reservoir.

Compressed air for tramway cars appears to have received an impulse in Wright's English patent, April, 1828; he also proposed the use of iron cylinders beneath the cars, with an additional cylinder for heating the air by a small furnace, to increase its expansive force before entering the working cylinder and to mingle steam generated by the same furnace with the hot air.

The air brake seems to have first taken shape at this time in Wright's patent with an eccentric on a wheel shaft, connected with a piston, which was to be operated as a brake on downgrades by pumping air into the air chambers; but it was not until 1869 that air brakes began to take a practical form under the patents of Westinghouse.

In 1828, Bompas, in England, patented and built a compressed-air locomotive.

Parsey, in 1847, built and ran a vehicle in which an intermediate reservoir was provided for reducing and equalizing the air pressure to the cylinders. Baron von Rathlen built and ran a vehicle with compressed air in England in 1848, attaining a speed of 12 miles per hour on the best roads of that day; he also suggested an increased pressure to 750 pounds per square inch as desirable for road and locomotive power, and advised compound compression and intercooling.

The earliest known appliance for making ice by the expansion of compressed air was invented and put into actual practice by Dr. John Gorrie, of New Orleans, La., in 1850, to whom a patent was issued in 1851. The system of cold-room storage by the expansion of compressed air has since been greatly enlarged on the lines originated by Dr. Gorrie, and is in use in the meat and fruit transport service.

Vallance again agitated the subject of tube transmission in England, in 1818 and on, and proposed a cast-iron tube system for passengers and parcels; followed by others with feeble efforts to establish the pneumatic tube system from about 1824; and again by William Mann with English patents in 1824.

It was not until about 1865 that practical success was achieved by the Parcel Dispatch Company of London; since then the use of this system for parcel and postal transmission has been greatly developed in Europe and in the United States.

The first compound compression of air was probably suggested in the patent to William Mann in 1829, for what was then called stage pumping,—*i.e.*, the use of two or more cylinders with intercooling; which was then properly claimed not only to effect great economy in compressing air, but also to decrease the machinery strain and to admit of lighter construction of the compressor.

In 1830 and on, Clegg and Pinkus, in England, agitated the system of a slotted tube and travelling piston with a vacuum or

air pressure, with connections to an outside carriage. Experiments were carried on through several years without success, although trials were made with short lines of slotted air tubes in England and Ireland.

In 1830, Thilorier compressed gases to high pressures in stages, for which he received a medal from the French Academy.

The air-plunger pump for producing fire by compressed air was a family adjunct before friction matches came into use, in the home of the writer's father, who, in 1833, employed an apparatus made by himself, consisting of a cast-iron barrel weighing several pounds, with a bore three-eighths of an inch in diameter, like a cannon without the vent. A steel piston, about eight inches long, was accurately and tightly fitted, but moved rather easily when lubricated. The end of the piston had a small cavity for receiving a piece of punk; the handle was provided with a stop or shoulder to prevent the plunger from striking the bottom in its sudden movement. The weight of the barrel, pushed by hand, acted by its momentum to complete the final pressure of, probably, eight hundred or more pounds per square inch, with an instantaneous evolution of temperature to a red heat, which fired the punk. A quick withdrawal of the plunger and the touch of a sulphur match completed the operation of generating a fire.

Following the agitation of the slotted-tube system of Clegg and Pinkus, in 1830, the subject was revived by Count Fontainemoreau, in 1844, and trials were made with unsatisfactory results.

The parcel-tube transmission system was again brought to the surface in England about 1860. A thirty-inch tube, a quarter of a mile in length, was constructed at Battersea, and afterward removed to London and used for conveying the mail between district offices.

This was followed in 1864 by a larger and longer line in London.

The trials of Mr. A. E. Beach in New York, in 1867, with an eight-foot subway under Broadway for the propulsion of passenger cars by air pressure, seemed a step in the right direction, and failed only from apathy in financial circles.

The pneumatic-tube system simply slumbered for a time, and was then developed into its most useful work; at the present time it is largely in use for interpostal and telegraphic-office connections throughout Europe and the United States. The store cash system, in its intricate detail, promptness, and accuracy, is a modern wonder.

Compressed air for machine-driving, crane-hoisting, and other mechanical purposes was agitated in England in 1840 and on, with patents on detail plants for the transmission of compressed air from a central station to distant hoisting engines in warehouses and on docks. Ericsson, in 1858, compressed air by the power of caloric engines, for operating hoisting-engines in warehouses in New York, followed by a practical system for running sewing-machines in large numbers from a central station by the transmission of compressed air to small motors on the machines.

Compressed air for high working pressures, generated by hydraulic pressure and the use of waterfalls, was an improvement on the antiquated methods by the use of the trompe.

The direct pressure system was brought into use by Sommeiller at the Mont Cenis tunnel in 1872, and did good work at that time; but as it required as much water to compress the air as was equal to the amount of free air compressed, the system was applicable only in favorable localities, and has now dropped out of use. Many patents have since been issued on direct-acting hydraulic air compressors, but the principle is not economical in practice, and we know of no compressors of this class in use at the present time.

The trompe system has been greatly improved and extended for high pressure, with a large flow of water with moderate head, by making a deep pit with an air chamber at the bottom

and returning the water to the foot-fall as in an inverted siphon. This was first demonstrated in experiments by Mr. J. P. Fizell, of Boston, in 1877, and patented in 1878. It has been finally put in practical operation by Mr. C. H. Taylor in large instalments of hydraulic plants at Magog, near Montreal, and at Ainsworth, British Columbia.

Both plants have proved a success, and the utilization of water power for compression of air and its transmission for all power purposes is thereby assured.

The vertical excavated shafts may not be needed where steep slopes, or chasms, or mountain sides are available. The moving water will carry air down a slope as well as by vertical shaft, and the return pipe only follows the same line back, so that the friction due to the additional length of flow line is the only loss in efficiency.

Compressed air for street railways was continually agitated by newspapers and promoters during the middle of the nineteenth century. But little practical progress was made, much of the difficulties and obstructions being due probably to the distrust of the moneyed interest of schemes that had no practical and reliable tests and trials.

In 1862 the writer made plans for a light car street-railway system with compressed-air storage under the seats and on top of the car, with the engine under the platform, so that the passenger accommodation was not interfered with. The air pressure of two hundred and fifty pounds was to be supplied from station storage tanks and a compressor on the line. The plans did not meet with financial encouragement, and proved to be premature. The horse was not yet ready to go. Another generation was needed to bring compressed-air power for railways to a financial acceptance.

Further progress was made about 1873 in the intercooling of the compressing air in the cylinders by water jets or sprays, in the compressors at the St. Gothard tunnel. This led to still further improvements and economics in the construction of air-

compressing machines; until at the present day there seems to be nothing but change of detail in construction—that may not always result in improvement.

The introduction of compressed-air-hauling locomotives in the St. Gothard tunnel was a successful turn in favor of compressed air for railway work, and seemed to stimulate efforts in that direction; it was soon followed by the Mekarski and Beaumont compressed-air railway systems in Europe, with increased air pressure and better appliances for economical compression and motor use. Compressed-air locomotives for mine haulage continued to improve in constructive details, and are now largely in use in the United States. For mining purposes compressed-air appliances have been steadily perfected, until at the present day there seems to be little room left for greater improvement except changes in detail, if such can be really called improvement.

The use of compressed-air machinery for quarrying, mining, and tunnelling, and the means of compressing air along economical lines, have been greatly extended by the inventive genius of Burleigh, Ingersoll, Sergeant, Rand, Clayton, and others, who have contributed to and promoted the economy of practical operation in rock-boring machinery that has so greatly aided in excavating the vast system of railway tunnels of the United States, and in sinking and drifting in the mines of all countries during the past quarter of a century.

Every implement required in the generation of compressed-air power and its uses has overflowed its earlier and narrow field of work, and is now encompassing a wide area of usefulness in our workshops, factories, and in hundreds of industrial operations: transportation, railway appliances, refrigeration—even unto the painting of buildings and structural work, and the dusting of furniture, carpets, and clothing.

The later development and actual application of compressed air at extremely high pressures, and its economical use by reheating, derived from the persistent efforts of Mekarski,

Beaumont, and others in Europe, and of Judson, Hoadley, Knight, and Hardie in the United States, have brought the use of compressed air to a new condition of application, and a high-pressure storage of 2,500 or more pounds per square inch in a condensed space of from 170 to 180 volumes in one volume. This allows for sufficient storage volume within the limit of passenger-car and vehicle capacity for runs of reasonable distances.

The precise limit of the compressibility of air at ordinary temperatures is as yet an unknown quantity. It has been compressed to 14,000 pounds per square inch in experiments for blasting rock; and it has been asserted, and there seems to be no reason to doubt, that any pressure may be obtained within the limit of safety in the strength of metals to hold the pressure.

The assertion has been made by experimenters with high air pressures that 20,000 or more pounds per square inch may be made available for special purposes; this is far below the explosive power of gunpowder.

The blasting effect of air at high pressure in coal mines was noted in a series of trials at Denton and Wigan, England, in 1877-79.

During these trials a pressure of 14,200 pounds per square inch was attained by the comparatively crude methods of those days. As compared with powder, the trials were successful in the saving of time and in the health and safety of the men; but the cost of production exceeded that of explosives, and the scheme was abandoned.

The experiments in high air pressures conducted by Mr. Perkins, a noted engineer, in England, and detailed in a paper read to the Royal Society, June 15, 1826, are most interesting, as demonstrating the liquefaction of air at ordinary temperature.

Mr. Perkins used a cast-steel pump, tested to 2,000 atmospheres, nearly 30,000 pounds per square inch, with water. Using the same pump for air, he observed the then curious

phenomena that induced him to carry the compression of air to the highest limit possible.

At 500 atmospheres, nearly 7,500 pounds, the air began to disappear, apparently by partial liquefaction; at 800 atmospheres, still further liquefaction was observed; at 1,000 atmospheres, 14,700 pounds, small globules of liquid air formed in the tube; and at 1,200 atmospheres, 17,640 pounds per square inch, a beautiful transparent liquid was seen in the glass compression tube.

Few attempts were made to liquefy air for many years succeeding Perkins' experiments, until about 1877, when Raoul Pictet, Cailletet, Dewar, Olzewski, and others followed in the line of producing liquid air by the cold or low-temperature process and moderate-compression system.

Michael Faraday had been experimenting on the liquefaction of air and other gases since 1823 with indifferent results. More recently Professor Linde, in Germany, has by improved and larger appliances liquefied air in large quantities.

Tripler and others in the United States have made liquid air a commercial commodity.

Its practicability as a motive power has been doubtfully questioned, and even ridiculed; but the fact is in evidence that it has the qualifications of a power mover, and can be controlled for any required pressure. Its practicability and economy are now being tested; as a refrigerant, its power is amazing.

The number of United States patents for compressed-air devices and appliances has gradually increased during the past century, and is now upward of four thousand.

Chapter II.

THE PHYSICAL PROPERTIES OF AIR

THE PHYSICAL PROPERTIES OF AIR.

AIR as it exists at and near the surface of the earth is a mechanical compound or mixture of several gases, principally nitrogen, filling 79 parts by volume, or 77 parts by weight, and oxygen, approximately 21 parts by volume, or 23 parts by weight. The relative volumes of nitrogen vary to an amount of about five per cent in different localities.

In air expelled from water by heating, Bunsen found 34.9 parts by volume of oxygen and 65.1 parts by volume of nitrogen. This change, made by contact with water, in the constituent volumes of air may be partly accounted for by the absorption of the carbonic acid gas and the formation of ammonia from the nitrogen of the air and hydrogen from the water, which would liberate oxygen.

This singular change in the constituents of air, when absorbed by water, may have an important bearing upon the existence of marine life that we have not yet seen discussed.

A minute percentage of from .002 to .005 of carbonic acid gas, a lesser amount of ammonia, and the newly discovered argon, amounting to about one per cent. in volume, are always present in air. The vapor of water is ever present in the atmosphere at seldom less than 50 per cent of saturation, at which point it holds .00044 of a pound of water per cubic foot of air at 62° F.; and at the point of saturation and temperature of 62° F. it holds .00088 of a pound per cubic foot of air.

The expression of "dry air," used by our air-compressor friends, is only relative, and air can only be considered dry when the amount of moisture is at less than 50 per cent of saturation for any given temperature; the amount of moisture actually varies with the temperature to three times less at 32° F. to three times more than the above figures at 92° F.

Air is absorbed by water in a decreasing ratio from 32° F. upward to a temperature at which vapor becomes visible and at atmospheric temperature. Increased absorption of air by water takes place under increasing pressure; hence, the frequent loss of air in the air chambers of pumping-machines and water rams.

TABLE I.—COMPARATIVE VOLUME OF AIR ABSORBED BY WATER AT VARIOUS TEMPERATURES, IN VOLUMES.

32 F.....	0.02471	68 F.....	0.01704
41.....	.02179	77.....	.01632
50.....	.01953	86.....	.01556
59.....	.01795		

To the loss of air in free running water at the higher temperatures in the table is probably due the insipidity of such water as compared with its taste between the temperatures of 32° and 41° F.

The weight of absolutely dry air at the sea level in middle latitudes and mean barometric pressure of 29.92 inches and at 32° F., is .080728 pounds per cubic foot; at 62° F. it weighs .0761 pounds per cubic foot, and is 819.5 times lighter than water, which weighs 62.355 pounds per cubic foot at the same temperature, viz., 62° F.

Air at the barometric pressure of 29.92 inches, 14.7 pounds per square inch, or 2166.8 pounds per square foot, and at the temperature of 62° F., requires 13.141 cubic feet to equal 1 pound avoirdupois; and in ordinary computation these figures are used for the normal conditions of the atmosphere at sea level in mid-latitudes.

If its whole volume were of equal density with the above pressure (14.7) at sea level, its limit of height would be $\frac{2116.8}{.0761}$, equal to 27,816 feet, a quantity used in computing for atmospheric head (h) in the formulas for the flow of air through orifices at a mean temperature of 62° F.

The height of the atmosphere appears to have no determinate limit, but it gradually fades away in density and pressure to its confines with interplanetary space. At about forty miles the

refractive effect of twilight ceases; above that elevation the air is either too rare or too pure from foreign particles to send us any perceptible reflection or illumination.

There is abundant evidence, however, from the phenomena of meteors that the atmosphere extends to a height of one hundred miles at least, and it cannot be asserted positively that it has any well-defined upper limit.

By virtue of the expansive force of the air, it might be supposed that the air in the upper atmosphere would expand indefinitely into the planetary space. But there are opposing forces that seem to limit its expansion. In proportion as the air expands in the upper regions of the atmosphere its expansive force is weakened and decreased by loss of heat, which partially counteracts its expansion, and with gravity probably holds its limit near the zone of absolute zero of temperature.

Below the level of the sea, as in the valley of the Dead Sea and in the shafts and adits of deep mines, the density of the atmosphere increases in the same ratio as above the sea level for equal temperatures and humidity. Such depths are indicated by the barometer under the same conditions as for the upper atmosphere.

The atmosphere obeys the law of compression and expansion when kept at a constant temperature, as found by Boyle and Mariotte, called Boyle's law, or the first law of dynamics. By this law the density of air and the atmosphere under compression, whether from the gravity of its own weight or by artificial compression, is directly proportional to the pressure to which it is subjected, when its temperature is constant or at the same temperature throughout the change of volume. It follows that when the height above the sea level increases by equal intervals and for equal temperatures the density of the air decreases in a geometrical ratio: thus, a cubic foot of air at sea level will become two cubic feet at about 18,000 feet above the sea, and four cubic feet at about 36,000 feet. This condition of tenuity of the atmosphere at great heights is shown in

the scanty vegetation, and the difficulty of sustaining life in the attempts to climb to the dizzy altitudes of our highest mountains.

In the process of compressing air under the ordinary conditions of the atmosphere, it becomes heated by compression; and on cooling in the compressed state becomes saturated by the narrowing limits of the moisture or water vapor held in the free air; and on further cooling the excess of moisture is set free as water in the reservoirs or pipes containing the compressed air.

For convenience of reference in regard to the relations of air and its contained moisture, the following table shows these conditions for differences of 10° F. from zero to the boiling-point of water:

Table II. Column 2 gives the comparative volume of free air at different temperatures from its volume of 1. at 32° F.

Column 3.—The weight of one cubic foot of absolutely dry air at the temperatures in the first column.

Column 4.—The elastic force of the vapor of water alone in inches of mercury at the temperatures in the first column.

Column 5.—The elastic force of the air alone in a saturated mixture of air and vapor in inches of mercury. Its values are obtained by subtracting the elastic force in column 4 from the standard barometric pressure at sea level; viz., 29.92 — column 4 = column 5.

Column 6.—Represents the weight of the air alone in a saturated mixture of air and vapor; it is obtained by the product of the weight of a cube foot of dry air in column 3 and the elastic force of air alone in column 5, divided by the standard barometric pressure of 29.921: $\frac{\text{col. 3} \times \text{col. 5}}{29.921} = \text{col. 6}.$

Column 7.—Is the weight in decimals of a pound of vapor contained in one cubic foot of saturated air at temperatures from 0° F. to 212° F., and is obtained by dividing the product of column 3 and column 4 by the standard barometric pressure at sea level (29.921), and multiplying the quotient by the relative

TABLE II.—RELATIVE VOLUME-WEIGHT OF DRY AND SATURATED AIR AND VAPOUR, WITH ELASTIC FORCE AT DIFFERENT TEMPERATURES IN ATMOSPHERIC PRESSURE AT SEA LEVEL, OR 29.921 INCHES BY BAROMETER. (Regnault.)

1	2	3	4	AIR SATURATED WITH VAPOUR.						11
				5	6	7	8	9	10	
Temperature, Fahrenheit.	Volume of dry air at temperatures in first column.	Weight of one cubic foot dry air at temperature in first column. Pounds.	Elastic force of vapor alone. Inches of mercury.	Elastic force of the air alone in the mixture. Inches of mercury.	Weight in one cubic foot of saturated air.	Weight of the vapor in pounds.	Total weight. Pounds.	Weight of vapor in one pound of saturated air.	Weight of dry air for saturation with one pound of vapor.	Cubic feet of vapor in one pound of water at elastic force in column four.
0	0.935	0.0864	0.044	29.877	.0863	.000079	.086379	.00092	1092.14	12.658.0
12	.960	.0842	.074	29.849	.0840	.000130	.084130	.00155	646.15	7.662.0
22	.980	.0824	.118	29.803	.0821	.000202	.082302	.00245	495.0	4.950.0
32	1.000	.0807	.181	29.740	.0802	.000304	.080504	.00379	263.81	3.259.0
42	1.020	*.0791	.267	29.654	.0784	.000440	.078840	.00561	178.18	2.252.0
52	1.042	.0776	.388	29.533	.0766	.000627	.077227	.00819	122.17	1.505.0
62	1.061	.0761	.556	29.305	.0747	.000881	.075581	.01179	84.79	1.135.0
72	1.082	.0747	.785	29.136	.0727	.001221	.073921	.01680	59.54	819.0
82	1.102	.0733	1.092	28.829	.0706	.001697	.072267	.02361	42.35	60.0.0
92	1.122	.0720	1.501	28.420	.0684	.002250	.070917	.03286	30.40	44.0
102	1.143	.0707	2.036	27.885	.0659	.002997	.068897	.04547	21.98	33.0
112	1.163	.0694	2.731	27.190	.0631	.003946	.067046	.06253	15.99	25.0
122	1.184	.0682	3.621	26.360	.0599	.005142	.065042	.08584	11.65	19.0
132	1.204	.0671	4.752	25.109	.0564	.006639	.063039	.11771	8.49	15.0
142	1.224	.0660	6.165	23.756	.0524	.008473	.060873	.16170	6.18	11.0
152	1.245	.0649	7.930	21.991	.0477	.010716	.058416	.22465	4.45	9.3
162	1.265	.0638	10.099	19.822	.0423	.013415	.055715	.31713	3.15	7.45
172	1.285	.0628	12.758	17.103	.0360	.016682	.052682	.46338	2.16	59.2
182	1.306	.0618	15.960	13.961	.0288	.020536	.049336	.71300	1.40	48.6
192	1.326	.0609	19.528	10.093	.0205	.025142	.045042	1.22643	.81	39.8
202	1.347	.0600	24.450	5.471	.0109	.030545	.041445	2.80230	.36	32.7
212	1.367	.0591	29.921	0.000	.0000	.036820	.036820	Infinite.	.00	27.1

weight of pure vapor with air, which is found to be .623 air
 i., viz., $\frac{\text{col. 3} \times \text{col. 4}}{29.921} \times .623 = \text{col. 7}.$

Column 8.—Equals col. 6 + col. 7 = the weight of one cubic foot of saturated air at the temperatures in column 1.

Column 9.—Shows the weight of the vapor of water in one pound of a saturated mixture of air and vapor at the temperatures in column 1. It is obtained by multiplying the weight of the vapor of one cubic foot in column 7, by the volume of one pound of air at the corresponding temperature, as found in column 2, table XIV., or by dividing col. 7 by col. 6: $\frac{\text{col. 7}}{\text{col. 6}} = \text{col. 9}.$
 Also, $\frac{\text{col. 6}}{\text{col. 7}} = \text{col. 10},$ which is the weight of dry air required to become saturated by one pound of vapor at the temperatures in column 1.

Column 11.—Represents the volume of vapor in cubic feet from one pound of water at the elastic force in inches of mercury in column 4; it is obtained by $\frac{1.}{\text{col. 7}} = \text{col. 11},$ or $\frac{\text{col. 10}}{\text{col. 6}} = \text{col. 11}.$

In Table III. is shown the amount of moisture in saturated air at pressures below that of normal atmospheric pressure, from 14.7 to the zero of absolute pressure, in troy grains per cubic foot at a temperature of 60° F. It shows at a glance the weight of the moisture in saturated air by the reduction of pressure to a vacuum.

TABLE III.—ABSOLUTE PRESSURE HEIGHT OF BAROMETER AND MOISTURE IN SATURATED AIR AT 60° F.

Average pressure to square inch.	Barometer, inches.	Troy grains, per cubic foot.	Average pressure to square inch.	Barometer, inches.	Troy grains, per cubic foot.
14.7	29.922	5.87	6.0	12.213	2.39
13	26.461	5.19	5	10.177	1.99
12	24.425	4.79	4	8.142	1.59
11	22.390	4.39	3	6.106	1.19
10	20.354	3.99	2	4.071	.79
9	18.319	5.59	1	2.035	.39
8	16.284	3.14	0	0	.0
7	14.248	2.79			

In Table IV. is shown the great increase in the amount of moisture held in saturated air in its rise of temperature from 32° to 94° F. The weight is given in troy grains to facilitate computation.

TABLE IV.—WEIGHT OF VAPOR IN ONE CUBIC FOOT OF AIR WHEN SATURATED BETWEEN TEMPERATURES OF 32° F. AND 94° F. 7,000 TROY GRAINS = 1 POUND AVOIRDUPOIS.

Temperature of air, Fahrenheit.	Weight, Troy grains.	Temperature of air, Fahrenheit.	Weight, Troy grains.	Temperature of air, Fahrenheit.	Weight, Troy grains.
32	2.37	56 ²	5.18	76 ²	9.60
35	2.63	58	5.51	78	10.19
38	2.89	60	5.87	80	10.81
41	3.19	62	6.25	82	11.47
44	3.52	64	6.65	84	12.17
46	3.76	66	7.08	86	12.91
48	4.01	68	7.53	88	13.68
50	4.28	70	8.00	90	14.50
52	4.56	72	8.50	92	15.33
54	4.86	74	9.04	94	16.22

For indicating the atmospheric pressure, the mercurial barometer of standard make is the only safe instrument, but

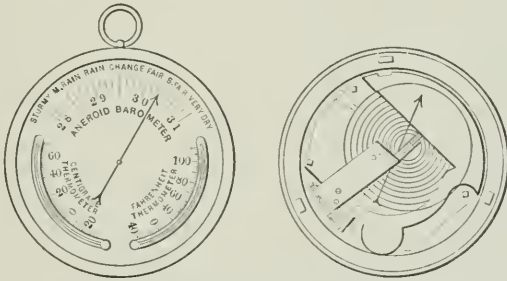


FIG. 1.—ANEROID BAROMETER.

for transportation and reconnoissance the aneroid is easily carried and is fairly reliable.

Its disked and corrugated vacuum chamber is attached to the index hand by levers through a toothed sector and held in position by a spring for correcting adjustment. The aneroids for mining purposes are provided with a special scale to indicate pressures from 2,000 or more feet below sea level to 5,000 or more feet above, and are also provided with a movable vernier scale for levelling.

TABLE V.—HEIGHT OF BAROMETER, GAUGE PRESSURE, BOILING TEMPERATURE OF WATER, AND APPROXIMATE HEIGHT IN FEET ABOVE THE LEVEL OF THE SEA, SUBJECT TO CORRECTION OF BAROMETER FOR SEA LEVEL. MEAN TEMPERATURE OF AIR, 60° F.

Barometer, inches.	Gauge pressure, absolute pounds.	Water boils, Fahrenheit.	Approximate height in feet.	Barometer, inches.	Gauge pressure, absolute pounds.	Water boils, Fahrenheit.	Approximate height in feet.
30.00	14.74	212.2°	0	22.73	11.16	198.5°	7,250
29.92	14.70	212.0	70	22.49	11.04	198.0	7,527
29.62	14.55	211.5	333	22.26	10.93	197.5	7,797
29.33	14.40	211.0	590	22.03	10.81	197.0	8,067
29.04	14.25	210.5	850	21.80	10.70	196.5	8,342
28.75	14.11	210.0	1,112	21.57	10.59	196.0	8,620
28.46	13.97	209.5	1,396	21.35	10.48	195.5	8,887
28.18	13.83	209.0	1,641	21.13	10.37	195.0	9,157
27.89	13.79	208.5	1,905	20.90	10.26	194.5	9,443
27.61	13.55	208.0	2,160	20.68	10.15	194.0	9,719
27.34	13.42	207.5	2,436	20.47	10.05	193.5	9,987
27.06	13.28	207.0	2,688	20.25	9.94	193.0	10,268
26.79	13.15	206.5	2,956	20.04	9.84	192.5	10,541
26.52	13.02	206.0	3,223	19.82	9.73	192.0	10,829
26.25	12.88	205.5	3,488	19.61	9.63	191.5	11,108
25.99	12.76	205.0	3,752	19.41	9.53	191.0	11,375
25.72	12.63	204.5	4,022	19.20	9.42	190.5	11,659
25.46	12.50	204.0	4,287	19.00	9.33	190.0	11,933
25.20	12.37	203.5	4,556	18.79	9.22	189.5	12,224
24.94	12.23	203.0	4,827	18.59	9.12	189.0	12,503
24.69	12.12	202.5	5,089	18.39	9.03	188.5	12,786
24.44	12.00	202.0	5,357	18.19	8.93	188.0	13,071
24.19	11.88	201.5	5,625	18.00	8.83	187.5	13,346
23.94	11.75	201.0	5,895	17.81	8.74	187.0	13,623
23.69	11.63	200.5	6,168	17.61	8.64	186.5	13,917
23.45	11.51	200.0	6,437	17.42	8.55	186.0	14,202
23.21	11.39	199.5	6,706	17.23	8.46	185.5	14,488
22.97	11.28	199.0	6,976	17.05	8.36	185.0	14,763

The barometric table (V.) is an abstract from the physical tables of the Smithsonian Institution, and is approximately correct, an extension of the decimals being dropped with the intervening numbers for barometric height. The intervals, as noted, are so nearly proportional that all the columns may be interpolated between the numbers given for any height of the barometer or boiling-point of water. The column of gauge pressure is also convenient for reference when required. For ascertaining differences in height, subtract the height due to the observation of the barometer at the lower station from the height due to the observed barometer reading at the upper station; the difference is the approximate height between the

stations. The same is also applicable for observation of the temperature of boiling water.

For accurate measurements, there are small variations and corrections which must be made for difference of latitude from 45° and for difference in temperature between the lower and upper stations, and a small correction for the lower station, which is only appreciable above 1,000 feet.

These corrections are collated in all their relations in the valuable work of the Smithsonian Institution, "Meteorological and Physical Tables," to which the author refers for accurate survey work.

CONDENSATION OF MOISTURE BY AIR COMPRESSION AND COOLING TO NORMAL TEMPERATURE.

For any hygrometric condition of the atmosphere, the weight of water that may be condensed by compression and cooling the compressed air to its normal temperature can be approximately found by simply multiplying the value for saturated air in one cubic foot, in Table II., column 7, by the hygrometric percentage, and this product multiplied by the number of volumes, less 1.

Table VI. has been computed for the temperatures in column 1 by the above formula, and as an example for other percentages and temperatures than found in the table; say, for a hygrometric percentage of 86 in free air, when compressed to 75 pounds per square inch from air at an external temperature of 62° F.; we find in column 3, Table VI., at 62° , the weight of water in 5 volumes (6 less 1), or cubic feet, to be .004405 pounds per cubic foot of compressed air at the point of saturation of free air; then $.004405 \times 86$ per cent = .0037883 pounds, which represents the weight of water that will be precipitated from 6 cubic feet of free air at 62° F. when compressed to 75 pounds gauge pressure and cooled to normal temperature. From Table VI., by interpolation, the amount of condensation of moisture may be approximately deduced, from the compression of any

number of cubic feet of free air per minute, at any temperature and pressure, when the compressed air is cooled to normal temperature.

TABLE VI.—SHOWING THE AMOUNT OF WATER THAT MAY CONDENSE IN POUNDS PER CUBIC FOOT OF COMPRESSED AIR AT VARIOUS PRESSURES, WHEN COOLED TO NORMAL TEMPERATURE, FROM SATURATED FREE AIR.

1	2	3	4	5	6	7	8
Compressed at temperature.	To 45 pounds or 4 volumes.	To 75 pounds or 6 volumes.	To 105 pounds or 8 volumes.	To 210 pounds or 15 volumes.	To 435 pounds or 30 volumes.	To 1,035 pounds or 70 volumes.	To 2,235 pounds or 150 volumes.
32 F.	.000912	.00152	.002128	.004256	.008816	.020976	.045296
42	.001320	.00220	.003080	.006160	.012760	.030360	.065560
52	.001881	.003135	.004389	.008778	.018188	.043263	.093423
62	.002643	.004405	.006167	.012334	.025549	.060789	.131269
72	.003663	.006105	.008547	.017094	.035309	.084249	.181929
82	.005001	.008335	.011669	.023338	.048343	.115023	.248383
92	.006750	.011250	.015750	.031500	.065250	.155250	.335250

The approximate percentage of water vapor in free air may be applied to the tabular figures, for the approximate weight of condensation for any hygrometric condition of the atmosphere for intervals of 10 degrees from 32° to 92° F. Barometer 29.92 inches.

For example: 500 cubic feet per minute at atmospheric temperature of 67° F., compressed to 75 pounds per square inch. Free air at 75 per cent. of saturation, which is about the mean condition of the atmosphere at or near sea level. Omitting the small increase in the ratio of saturation for the rise in temperature, the mean between 62° and 72° in column 3 will be found to be $.00525 \times .75$ for the percentage of saturation = $.0039375 \times 500$ cubic feet = 1.968 pounds of water condensed per minute.

For any other pressure than stated in Table VI., use the proportional difference between the stated amounts in the columns next to the required pressure for the approximate amount of condensation; also the rule as stated for any pressure.

Chapter III.

AIR IN MOTION AND ITS FORCE

AIR IN MOTION AND ITS FORCE.

THE power of air in the force of the wind was probably the earliest of the forces of nature captured by mankind and utilized in moving the first sail on the sea, and by its progressive use has contributed its vast power to extend the civilizing influence of commerce to every part of the world. Nor is its power confined to the gentle winds that waft the sails or turn the windmills; its terrors in the storm and the tornado are in constant evidence.

In our every-day uses the power of air is what we make it: we compress it, we bottle it up under vast pressures, in which its power is a potential element ready for work at our bidding.

The force of air in motion, the wind, was for ages the dominant power, and windmills dotted the land in all civilized countries. There was a time when the natural forces of wind and water were the only ones at the command of man for industrial purposes, and when the motors driven by these forces monopolized all industrial pursuits which man did not accomplish by his own physical exertion. It is still largely in use, and is probably the most economical power available within its limited sphere of action; it is obtainable in all parts of the world; the wind blows over every country.

VELOCITY AND PRESSURE OF THE WIND.

Observations on the velocity and pressure of the wind have been made under varying conditions as high as 159 feet per second, with a pressure of 57.75 pounds per square foot, from which it was found that the resistance to air in motion varied as the square of the velocity nearly, on surfaces with planes at right angles to the direction of the wind.

For inclined surfaces the resistance was found to be 1.84th power of the sine $\times$ the cosine of the angle.

The pressure of the wind varies slightly for given velocities with its density and temperature; so that with a high barometric pressure and low temperature, say for above 30 inches, the formula $.005 \times \text{area} \times \text{square of the velocity in miles per hour}$ may be used for the pressure per square foot, or $.0023 \times \text{area} \times \text{square of the velocity in feet per second} = \text{pressure in pounds per square foot}$.

For mean barometric pressure and temperature of 35° F. , $.005 \times \text{the square of the velocity in miles per hour}$ is in use, and from which the wind pressures in the following table, Table VII., have been computed. Also $\sqrt{200 P} = V.$, in which $P = \text{pressure in pounds per square foot}$, and $V = \text{velocity in miles per hour}$.

TABLE VII.—VELOCITY AND PRESSURE OF THE WIND. AT A BAROMETRIC PRESSURE OF 29.921 AND TEMPERATURE OF 32° F.

VELOCITY.			Pressure per square foot. Pounds.	Observed character of the wind.	VELOCITY.			Pressure per square foot. Pounds.	Observed character of the wind.
Miles per hour.	Feet per minute.	Feet per second.			Miles per hour.	Feet per minute.	Feet per second.		
1	88	1.47	.005	Barely observed.	16	1,408	23.48	1.291	
2	176	2.93	.020	Just perceptible.	17	1,496	24.93	1.458	
3	264	4.40	.045	Very light.	18	1,584	26.40	1.634	
4	352	5.87	.081	Light breeze.	19	1,672	27.86	1.821	
5	440	7.33	.126	Fair breeze.	20	1,760	29.33	2.018	
6	528	8.80	.181	Very fair breeze.	25	2,200	30.67	3.155	Very brisk.
7	616	10.27	.247		30	2,640	44.00	4.547	{ High wind.
8	704	11.73	.323	Fresh breeze.	35	3,080	51.33	6.194	
9	792	13.20	.408		40	3,520	58.67	8.099	Very high wind.
10	880	14.67	.505	Strong breeze.	45	3,960	66.00	10.260	Gale.
11	968	16.13	.610		50	4,400	73.33	12.684	Storm.
12	1,056	17.60	.726		60	5,280	88.00	18.310	Great storm.
13	1,144	19.07	.852		80	7,040	117.3	32.80	Hurricane.
14	1,296	20.53	.988		90	7,920	132.0	40.50	{ Tornado.
15	1,320	22.00	1.135	Stiff breeze.	100	8,800	146.6	50.00	

There is a variation in pressure, due to temperature, amounting to about 1.7 per cent of the tabulated pressures, which are additive below 32° F. , and subtractive above, for each 10° F. ; so that in a hurricane at 80 miles an hour, with the

thermometer at 90° , the pressure would be 29.16 pounds per square foot, instead of 32.8 in the table.

The wind pressure on spherical surfaces is approximately 0.36, that on a plane circular surface of the same diameter, as in Fig. 2. On a cylindrical surface of a length equal to its diameter the wind pressure is equal to 0.5 that on a plane surface equal to the diameter and length of the cylinder; hence the power that operates the cupped or curved blade anemometers and horizontal windmills. The curved blades, as shown in Fig. 3, represent the principle of the action of the wind on curved surfaces.

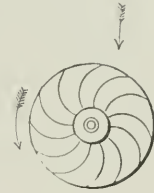


FIG. 2.—CURVED VANE WINDMILL.

As a windmill, this form, as well as mills made with flat, inclined blades revolving on a vertical axis, are very much weaker in power than the vertical plane form, as shown in Fig. 5, which has been found to possess a higher efficiency than any of the windmills of other forms.

The measurement of the velocity and force of the wind is approximately obtained by the use of anemometers of various kinds for the velocity and by resistance planes for its force. The Robinson four-armed cup form, used by the United States Weather Bureau, is generally accepted as the best form for a stationary anemometer. The small Davis or Biram windmill anemometers, with gear and dials adjusted for indicating the velocity of air currents in mines or ventilating passages, are much in use and fairly reliable.

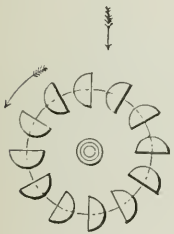


FIG. 3.—ANEMOMETER.

With the cup anemometer the experiments of Dr. Robinson and others on the difference in force of the wind upon the spherical and hollow side of a cup resulted in finding that the pressure for all wind velocities was four times as much on the concave side as upon the convex side.

By differentiating the pressures, it was found that the velocity of the wind was about three times the velocity of the

centre of the cups, not including the friction, which is a variable factor to a small extent, slightly increasing with the velocity of the wind. The ratio for the differential pressure and friction in the standard cup anemometers of 4

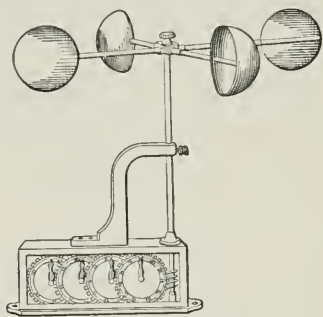


FIG. 4.—ROBINSON'S ANEMOMETER.

inches cup diameter and 7-inch radius to their centres, is 3, from which their dial gear is computed.

In Fig. 4 is shown the general construction and arrangement of the index train of a Robinson anemometer. Each dial is graduated respectively to 0.1 mile, 1 mile, 10 miles, 100 miles, 1,000 miles, and these revolve behind fixed indexes,

the readings of which are taken according to the indication on the faces under the indexes. Observations are recorded by differentiating the readings of the dials and multiplying by the observed time. A most convenient way is to record the readings of the dials at intervals of 12 minutes and divide their difference by 10 for the velocity of the wind in miles per hour.

The Biram anemometer (Fig. 5) is much in use for testing the velocity of the air current in the ventilation of mines, hospitals, schools, and public buildings.

For testing the volume of air passing in a ventilating flue or air-shaft of a mine, select a place having a uniform section; let the instrument run a short time to gain full speed; then test it one minute by a watch and note the velocity, as indicated by the difference of the two dial readings

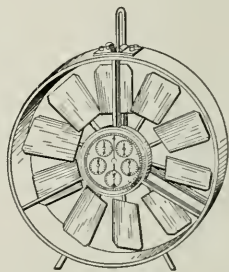


FIG. 5.—BIRAM ANEMOMETER.

at the beginning and end of a minute; then multiply the area of the flue or air-shaft in square feet by the velocity in feet per minute for the cubic feet per minute. In some of the States the law requires a supply of 100 cubic feet of air per

man per minute, and as much more as the special condition of the mine may require.

The direct pressure of air currents up to about 6 inches for water, or $\frac{2.16}{1000}$ of a pound per square inch, and indicating velocities up to near 80 miles per hour, is readily obtained by Lind's siphon pressure gauge, shown in Fig. 6. It consists of a glass siphon, with parallel limbs, mounted upon a vertical rod, on which it moves freely by the action of the vane which surmounts it. The upper part of one of the limbs is bent outward toward the wind. Between the limbs is a graduated scale, indicating from 0 to 3 inches in 10ths, the zero being in the centre of the scale. In use, the tube is filled with water to the zero of the scale and exposed to the action of the wind, by which the water is depressed in the one limb and raised in the other. The sum of the elevation and depression is the height of the column which the wind is capable of sustaining.

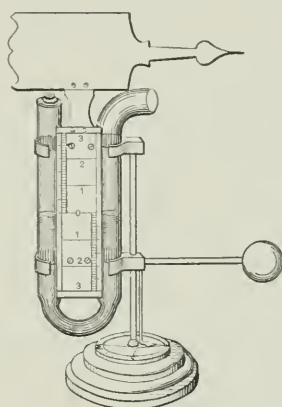


FIG. 6.—THE SIPHON PRESSURE GAUGE.

The pressure indicated is .036 of a pound per square inch per inch of difference in the level of the two legs of the siphon, or 5.18 pounds per square foot. Then each division of one-tenth of an inch will represent .518 of a pound per square foot, and by reference to the wind-pressure column in Table VII. the approximate velocity of the wind for any pressure may be found. This also corresponds with the velocities derived from water pressure in Table X.

The capacity of air for evaporating water varies greatly, depending upon the temperature of the water, the relative temperature of the air, its humidity, and its velocity over the surface. These four conditions vary the effect one with another, so that from the following table of observed evaporation for even temperatures of both air and water and for

degrees of humidity by tenths, a fair estimate may be made for different conditions:

TABLE VIII.—EVAPORATION AT EVEN TEMPERATURES OF WATER AND AIR AND AT DIFFERENT STATES OF HUMIDITY OF THE AIR, IN GRAINS PER SQUARE FOOT PER HOUR, IN CALM AIR. (Box.)

Temperature of air and water.	HUMIDITY OF THE AIR; SATURATION = 100.							
	Dry.	30	40	50	60	70	80	90
32° F.	69	48	41	34	28	21	14	7
42	101	71	61	51	40	30	20	10
52	147	103	88	74	59	44	29	15
62	211	148	127	106	84	63	42	21
72	298	209	178	149	119	89	60	30
82	426	298	256	213	170	128	85	43
92	570	400	342	285	228	171	114	57

From experiments by Dr. Dalton, the increase of evaporation from a calm by a light wind of three or four miles per hour made an increase in the evaporation of 28 per cent, and from a fresh breeze of about 8 miles per hour made an increase of evaporation of 50 per cent for air of nearly the same temperature of the water. A warmer wind than the water will somewhat increase the evaporation and a colder wind will retard it.

Chapter IV.

AIR PRESSURES BELOW ATMOSPHERIC PRESSURE

AIR PRESSURES BELOW ATMOSPHERIC PRESSURE.

A VACUUM is the zero of atmospheric pressure, and is the beginning from which the absolute pressures start in many air problems; and, like the absolute zero of temperature, it is the point in the scale of pressure at which air expansion becomes infinite, and to which temperatures contract to the measure of interplanetary space.

One of the means by which the pressure of the atmosphere is reduced toward a vacuum is an air pump (Fig. 7). Its power to produce negative atmospheric pressures to a certain extent is complete; but is limited in ultimate results by the amount of the volume of clearance divided by the volume of the piston stroke.

At the point of the greatest exhaustion by an air pump the clearance volume expands by its elasticity as the piston recedes and fills the entire cylindrical space, so that the best mechanical pump can scarcely produce a vacuum of less than one-hundredth of an inch of mercury, and often one-tenth of an inch is the limit. Referring to the cut, the pump consists of two cylinders with pistons operated by racks on each side of a pinion and the oscillating motion of the handles *M N*. Each piston has a valve opening upward, and the base of the cylinder also has a valve opening upward at *c*; the cock at *Q* is to shut off one of the cylinders, and a cock at *S* shuts off both cylinders to prevent leakage; *r* is a relief valve. At *T* is a cock to shut off the mercury gauge *E*, which is a U-shaped glass tube with one end closed and the tube partly filled with mercury, and with a Torricellian vacuum in the closed end, and a gauge attached; the whole enclosed in a glass cover and connected with the cock *T*. The platform *I* is arranged to seal by contact the

various implements used in experimenting on the properties of air below atmospheric pressure.

The hydraulic air ejector, Venturi vacuum pump, or aspirator, is a most convenient instrument for quickly obtaining an approximate vacuum. In its construction the form of the curved nozzles is made after the suggestions first enunciated by Venturi, on the principle that a passing fluid at a high velocity through a converging and a diverging nozzle, in which

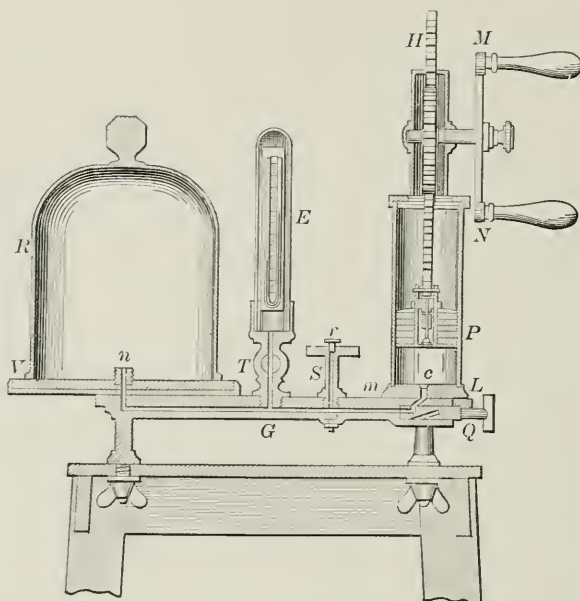


FIG. 7.—THE AIR PUMP.

the curves conform to the shape of the *vena contracta* of a jet from an orifice, will produce an approximate vacuum at a point near its greatest contraction, and if an air chamber is connected through an orifice at this point, the air will be discharged and nearly a perfect vacuum will be made in the air chamber. The water-entering nozzle may be connected by a rubber tube to any faucet of a town water-works, or from a tank having a head of more than 14 feet, or one-half the static water-head of a vacuum. The air-inlet leg requires an elastic valve, as shown in the cut, and a small bar occupying nearly one-half the area

of the water-exit end has been found necessary in practice for its more perfect action. The cut is an exact proportional form and one-half the dimensions of those in use in laboratory and experimental work. It is capable of producing a vacuum equal to the barometric height, less the height due to the tension of the vapor of water, which at 60° F. equals one-half inch of mercury; while at the temperature of the greatest density of water, a vacuum ranging within one-quarter of an inch of the barometric height due to the atmospheric pressure may be obtained.

The aspirator for various purposes has been made in several forms, following the principles of the hydraulic ejector and the steam injector for large volumes; but for general utility, this simple form has come into use for experimental work in educational institutions, and in the arts where an automatic and constant vacuum draft is needed. The aspirator is made by Mr. E. C. Chapman, 287 Gates Avenue, Brooklyn, N. Y.

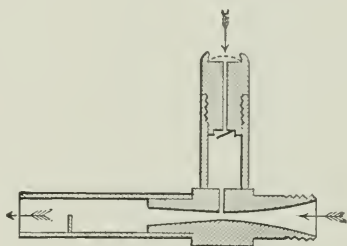


FIG. 8.—VENTURI VACUUM PUMP.

For a more perfect vacuum than the air pump or the hydraulic aspirator gives, the Sprengel mercurial air pump is found to produce nearly a Torricellian vacuum. One of the many forms of this pump we illustrate in Fig. 9, which can be readily constructed by any amateur of ordinary genius. The individual tubes are shown in the section to the right of the assembled instrument.

The materials necessary for the construction are as follows: A piece of soft glass tubing 5 ft. long, with a bore of about $\frac{3}{8}$ of an inch (1 centimetre); three pieces, each 5 ft. long, with a bore of $\frac{1}{16}$ of an inch, having fairly thick walls, say $\frac{1}{16}$ of an inch. If the bore is much over $\frac{1}{16}$ of an inch, the pump will not produce a good vacuum. Two or three feet of thick rubber hose to connect the pump with the vessel to be exhausted; a quart bottle, with the bottom cut off, and a brass screw clamp.

The large tube is to be drawn down to half its diameter about an inch from one end. The bore of this contracted portion should be too narrow to admit one of the smaller tubes. This allows of a cement joint of good sealing-wax, or a mixture of pitch and gutta-percha. The exhaust tube *E* should be joined to the *U* bend at *B* by welding the glass. The clip on

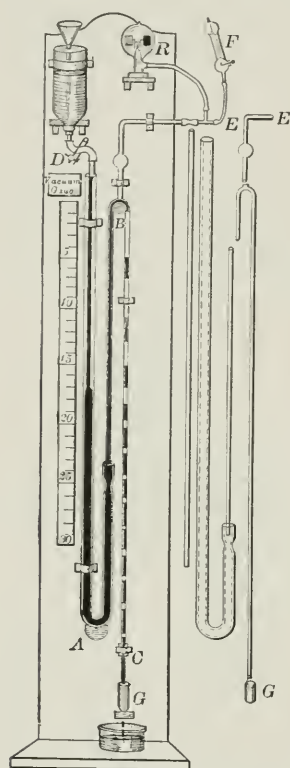


FIG. 9.—MERCURIAL AIR PUMP.

the rubber connecting-piece at *D* serves to regulate the flow of the mercury through the small tube within the large tube, and which should extend about 2 inches below the scale. The long leg of the large tube may be 36 inches in length. The *U* bend at *B* should be on a level with the zero mark on the inverted 30-inch scale. A small cup seals the end of the small tube at *G*. The overflow of mercury falling into the receptacle below, allows of its transfer to the bottle above through a funnel and filter of paper perforated at the bottom. The apparatus may be arranged on a board and the whole apportioned by the inch scale, as shown in the figure. *R* represents the attachment of a radiometer or an incandescent lamp, and *F* that of a Geissler tube.

To run the apparatus a good-sized cup of mercury will be required. The more mercury there is the less trouble there will be in continually transferring it from the basin to the reservoir. Close the clamp first, also stop the exhaust tube at *E*, then pour the mercury into the funnel. It will run through in a few minutes, leaving a black scum on the paper unless pure. Now open the cock a little and the tubes begin to fill, the fluid rising in a double column in the large and small tubes. As soon as it reaches the *T* it will flow

over and down, dragging air from the exhaust tube. Stop the flow. You will notice that the column in the large open tube does not rise above the T ; hence it cannot overflow. Make a paper scale, divided into 30 inches, and duly marked; paste this beside the large tube, so that the top of the scale is opposite the top of the mercurial column. Everything is now ready for the process of exhaustion. Connect the exhaust tube with the vessel (say a Geissler tube, F) by means of a piece of rubber tube, which should fit *very tightly* over the tubes. Open the clip a little and the drops of mercury immediately begin to tumble over the bend and go chasing each other down the long tube. They should go over quite slowly, say two a second, and the spaces between them will be quite long at first. Notice the mercury column in the large tube; it is falling rapidly, and by observing the scale you may know exactly how the exhaustion is proceeding. When the column reaches the 15-inch mark, exactly one-half of the air has been removed from the vessel. As the exhaustion proceeds, the air between the falling drops becomes thinner and thinner, and finally we have a solid column in the long tube, standing 30 inches above the surface of the cup G , upon which the drops fall with a sharp metallic click, and the column of mercury in the large tube will stand at the index of the barometric pressure. This hammering of the pump shows that the exhaustion is very perfect, the air being too thin to serve as an elastic cushion. The pump should be allowed to hammer away for a few minutes, when the vessel may be disconnected, either by fusing the glass tube connecting it with the hose or in any way that is desired. Care must be taken to keep the reservoir supplied by transferring the mercury from the basin to it. It is best to have two basins, and exchange them at intervals. With this pump, Geissler and Plucker tubes, or small electric light bulbs, may be exhausted, and any experiments requiring high vacua may be performed. A vacuum of $\frac{1}{300,000,000}$ of an atmosphere is claimed to have been made with this form of Sprengel pump.

The general principles of the combined condenser and air pump are shown in Fig. 10, in which *A* is the exhaust inlet to the condenser *F*, *B* the water inlet, and *D* the spray valve, which is adjusted by the valve wheel on the valve spindle at *E*, *G* the pump piston, *H* the suction valves, and *I* discharge valves; *K*, steam chest and valve.

In this class of injector condensers, from 27 to 30 times the weight of steam used in the engine must be furnished in water to the condenser. For instance, if an engine is using 20 pounds of steam per horse-power per hour, then 540 or more

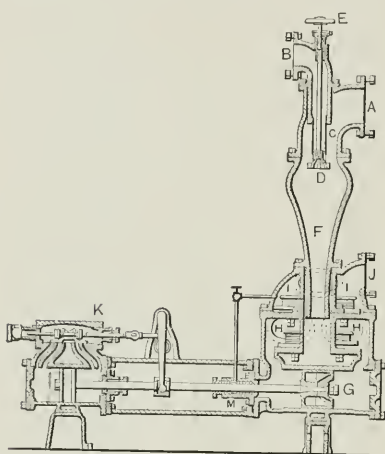


FIG. 10.—CONDENSER AND PUMP.

pounds of water, or 72 or more gallons of water per hour, must be provided for effectual condensation. The capacity of the air pump should exceed the water volume by about 50 per cent for effectual work and for maintaining a vacuum of 24 to 26 inches of mercury.

The steam vacuum or air pumps, as now constructed, of which Fig. 11 is a representative air pump and jet condenser,

made by Guild & Garrison, and Fig. 12 is a vacuum pump for the work of evaporation in vacuum pans, enables the production of a vacuum within one inch of the barometric height, and will maintain a vacuum of two inches less than the barometric height for steam power with a good condenser.

For evaporating and concentrating liquids and syrups, there is a considerable range in the amount of water that can be evaporated from various kinds of liquids and substances, owing to their degree of viscosity, which property seems to have a holding power on the water with which they are combined or saturated. The evaporation of natural water at normal temperatures under reduced atmospheric pressure is largely

increased from the conditions and temperatures shown in Table VIII. for open-air evaporation.

The experiments of Daniell show that the evaporation of

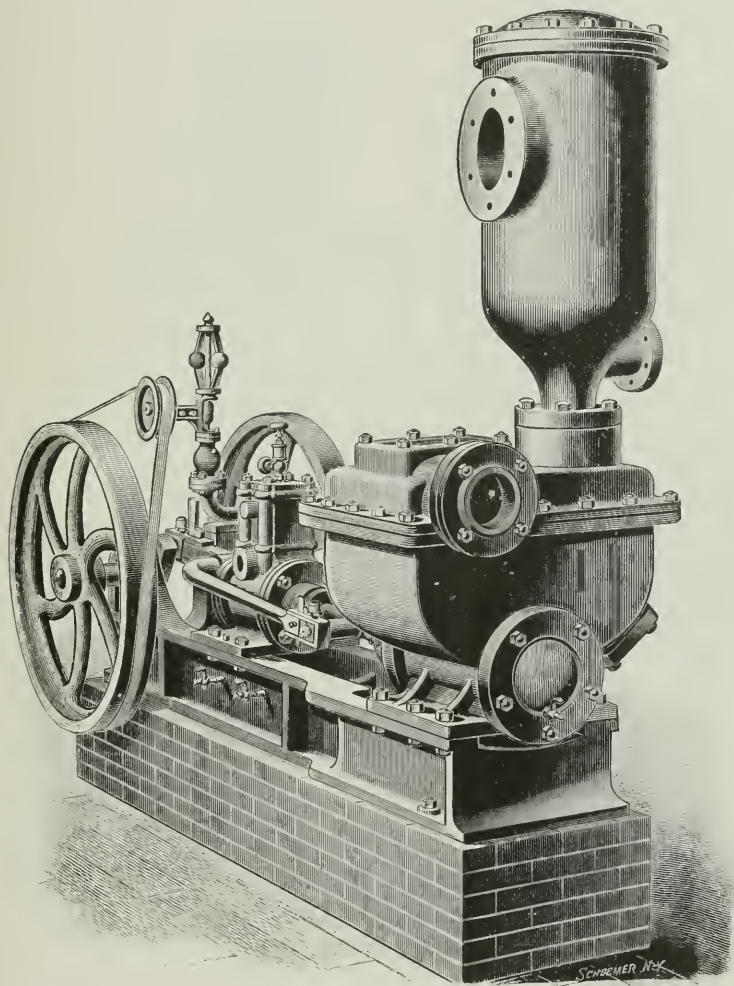


FIG. 11.—GUILD & GARRISON AIR PUMP AND JET CONDENSER.

water is nearly inversely proportioned to the pressure, so that at half the normal pressure the evaporation would be doubled. With a vacuum as nearly perfect as could be obtained, or $\frac{1}{434}$ of a normal barometric pressure, the evaporation is increased

about 70 times more than would be due to the evaporation at normal atmospheric pressure.

Referring to Table VIII. as a gauge for open-air evaporation,

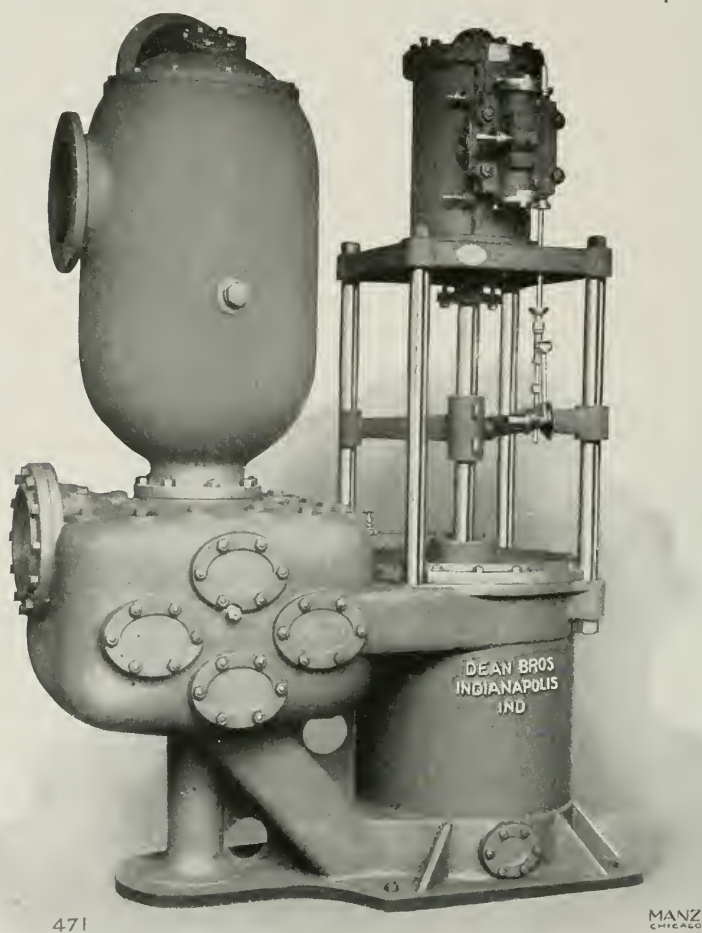


FIG. 12.—VERTICAL DOUBLE-ACTING AIR PUMP AND JET CONDENSER.

One of several types built by the Dean Brothers Steam Pump Works, Indianapolis, Ind.

and using the third column as representing the conditions at one-half atmospheric pressure, or barometer at 15 inches, temperature 62° , we would have an evaporating effect of 296 grains of water per square foot of surface per hour. The distillation

of water at higher temperatures and under a higher vacuum with a surface condenser is a most important item in the production of artificial ice, and by reducing the vacuum to $\frac{27}{30}$ and heating the water to its boiling-point under the vacuum, say 114° F., from 8 to 10 pounds of water may be evaporated per square foot of surface per hour.

TABLE IX. — BOILING AND VAPORIZING TEMPERATURES OF WATER, AT AND BELOW ATMOSPHERIC PRESSURE, WITH PRESSURES AND THE VOLUME OF ONE POUND OF VAPOR. (Clausel.)

Temperature, Fah.	PRESSURE.		Volume of one pound, cubic feet.	Temperature, Fah.	PRESSURE.		Volume of one pound, cubic feet.
	Mercury, inches.	Per square inch, pounds			Mercury, inches.	Per square inch, pounds.	
211°	29.92	14.70	27.2	120	3.43	1.68	204.9
210	28.75	14.42	28.2	115	2.97	1.46	234.7
205	25.99	12.77	31.0	110	2.57	1.27	268.1
200	23.46	11.52	34.1	105	2.23	1.09	307.7
195	21.14	10.38	37.6	100	1.91	.94	353.4
190	19.00	9.33	41.5	95	1.64	.81	408.2
185	17.04	8.37	45.9	90	1.41	.69	471.7
180	15.29	7.51	50.8	85	1.20	.59	549.5
175	13.65	6.71	56.4	80	1.02	.50	641.0
170	12.18	5.98	62.4	75	.87	.43	746.3
165	10.84	5.33	69.8	70	.73	.36	877.2
160	9.63	4.73	75.0	65	.62	.30	1031.0
155	8.53	4.19	87.3	60	.51	.25	1220.0
150	7.55	3.71	97.8	55	.42	.21	1429.0
145	6.66	3.27	110.0	50	.36	.18	1695.0
140	5.86	2.88	124.1	45	.30	.15	2041.0
135	5.17	2.54	140.1	40	.25	.12	2439.0
130	4.51	2.21	158.7	35	.20	.10	2941.0
125	3.93	1.93	180.5	32	.18	.09	3226.0

The steam or other power vacuum pump is the means of utilizing the work from a vacuum for commercial purposes.

Their use is a source of economy in all operations requiring a large amount of air to be withdrawn from an evaporating apparatus or to keep up the greatest tension possible when a large quantity of water is used for condensation, as it has been shown in previous chapters that water in its natural condition holds a considerable amount of air, which becomes liberated under a vacuum; hence the necessity of the use of a large vacuum pump where jet condensation is used.

In Fig. 13 is shown a vacuum pump of the Guild & Garrison type, much used in operating the triple effect sugar trains.

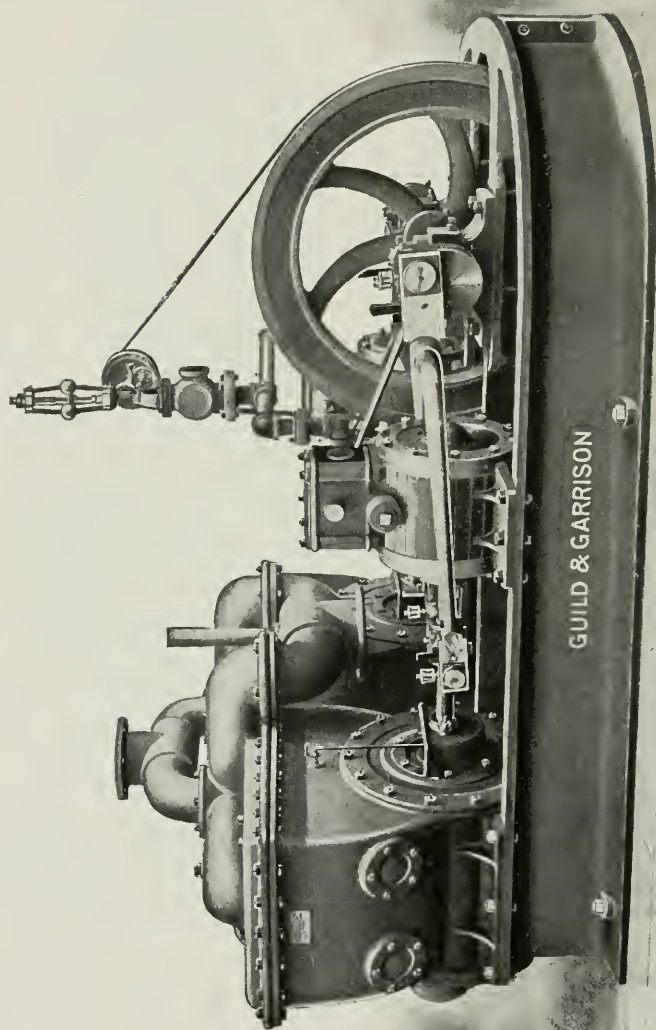


FIG. 13.—THE GUILD AND GARRISON VACUUM PUMP.

The large air head on this class of pumps is for the purpose of arranging the inlet and outlet valves above the cylinder, and to allow the clearance to be charged with solid water and to retain it, so that there shall be a perfect exit of the air above the water. To prevent shock by the water striking a level valve plate and to leave no space that can retain air, the exit-

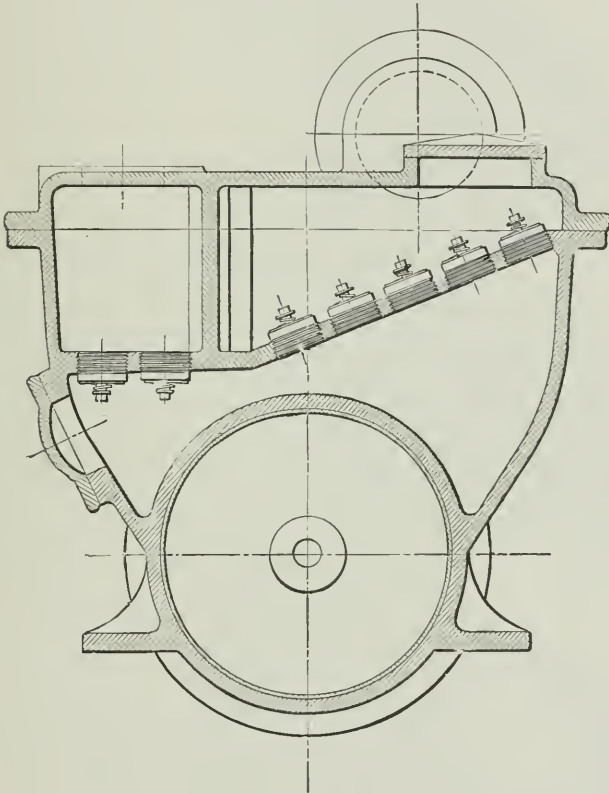


FIG. 14.—VACUUM PUMP CHAMBER.

valve plate is placed in an inclined position, as shown in Fig. 14, which allows every fraction of space to be closed by the clearance water at the end of each stroke of the pump.

In the "wet system" all the water used for condensation passes through the pump, while in the "dry system" the barometrical column, or leg pipe, carries off the injection water by gravity from the bottom of the condenser without passing

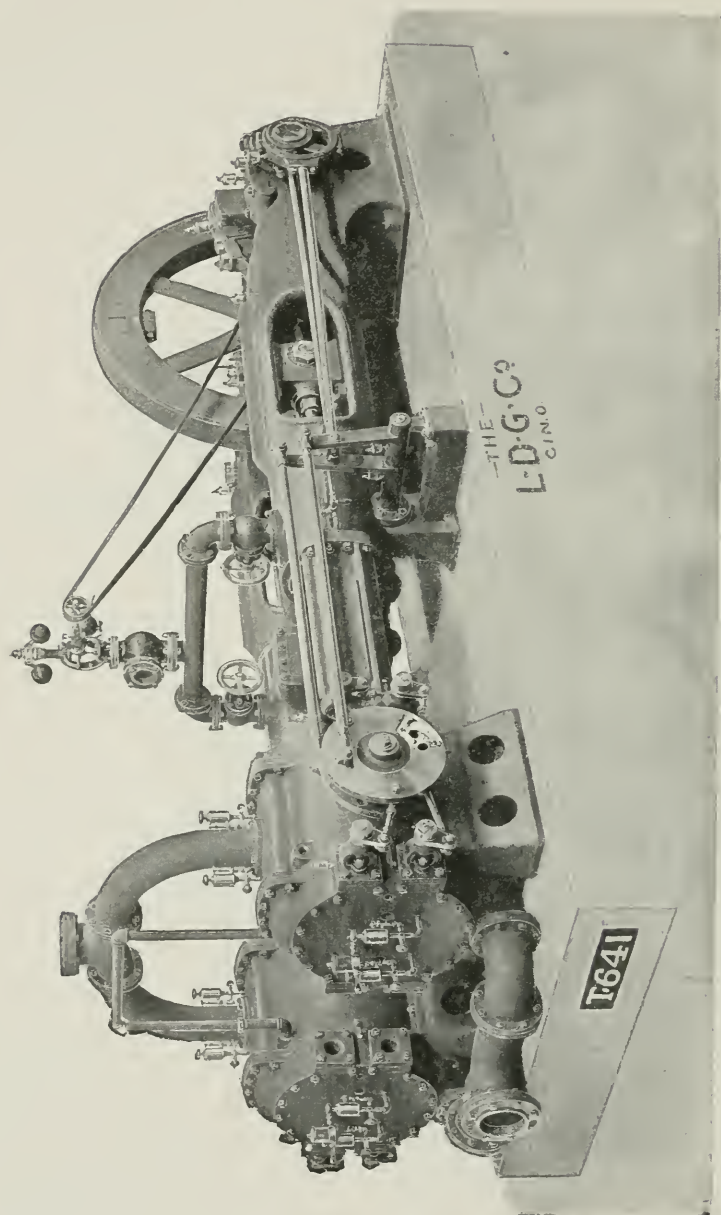


FIG. 15.—THE DUPLEX DRY VACUUM PUMP.
Fork frame pattern with Corliss valves, Laidlaw-Dunn-Gordon Co.

through the pump. The combined vacuum and water pumps are so arranged that when connected with a vacuum pan working on the "dry" system, the water cylinder of the pump is connected to deliver the injection water to the tank that feeds the condenser, or, if preferred, to the condenser direct. In Cuba and other places where the "cooling tower" is in vogue (the injection water being used over and over again), the water cylinder is arranged to take the warm water discharged by the

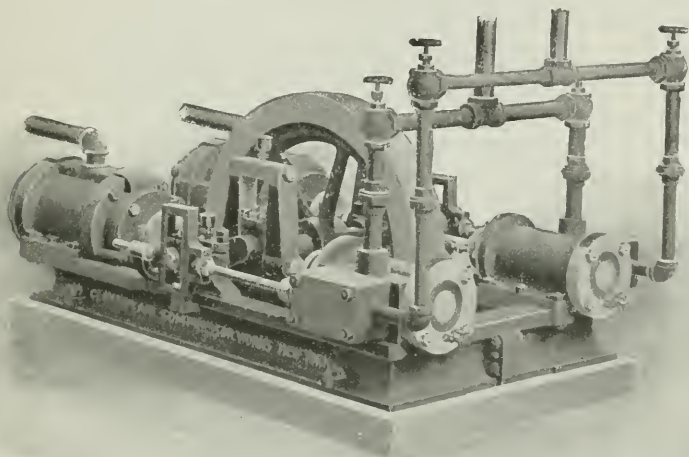


FIG. 16.—CLAYTON STEAM ACTUATED VACUUM PUMP.

air cylinder and deliver it to the "cooling tower." This is the general arrangement when working on the "wet" system.

Fig. 16 represents the duplex vacuum pump of the Clayton Air Compressor Works, New York City, in sizes ranging from 4-inch to 16-inch diameter of vacuum cylinder, with corresponding steam cylinders of less size; stroke from 3 to 15 inches. They are constructed with water-jacketed vacuum cylinders when desired.

Poppet valves are placed in the heads of the cylinders. Single vacuum pumps are made of the same sizes.

The Blake duplex fly-wheel vacuum pump is illustrated in

Fig. 17, in which the design of the vacuum cylinder and valves is such that the same pump may be used equally well for the wet or dry system of evaporation.

THE COMMERCIAL UTILITY OF A VACUUM.

The history of the vacuum in the United States Patent Office is an interesting one, dating back to 1833, in which year George H. Richards took out exclusive rights in a process for preparing leather from various substances by evaporation in vacuo at a temperature below 212° , the object being to avoid injuring the product by too great heat. This method is applied in obtaining flavors for sirups dispensed at soda-water fountains. It also serves in making extracts from malt and hops and from coffee. The fact is well known that firms engaged in the business of roasting coffee for market commonly deprive the beans of their volatile flavoring essence and sell the latter separately. An honest coffee roaster returns this essence to the beans. Much of it passes off during the ordinary cooking process, and thus it happens that at times the streets in the neighborhood of a coffee-roasting store are fragrant with the odor of coffee. It is agreeable to the nostrils, but very wasteful. A properly constructed roasting-machine saves and condenses the vapor.

Bakers use great quantities of egg meats dried in vacuum pans. The eggs are broken into the pans, the whites and yolks being separated. They are then evaporated to dryness, after which they are scraped from the pans and granulated by grinding. The product looks very much like sawdust; it is comparatively cheap, and will keep good for many months, taking the place of fresh eggs when the latter are scarce and dear. A similar process is employed in the manufacture of so-called "egg albumen," which is said to be composed largely of the whites of eggs. It looks like a fine quality of glue, being used by bakers and for glazing.

Several processes have been patented for preserving eggs in their shells by means of the vacuum. One method is to place them in a chamber, which is then exhausted of air. The air,

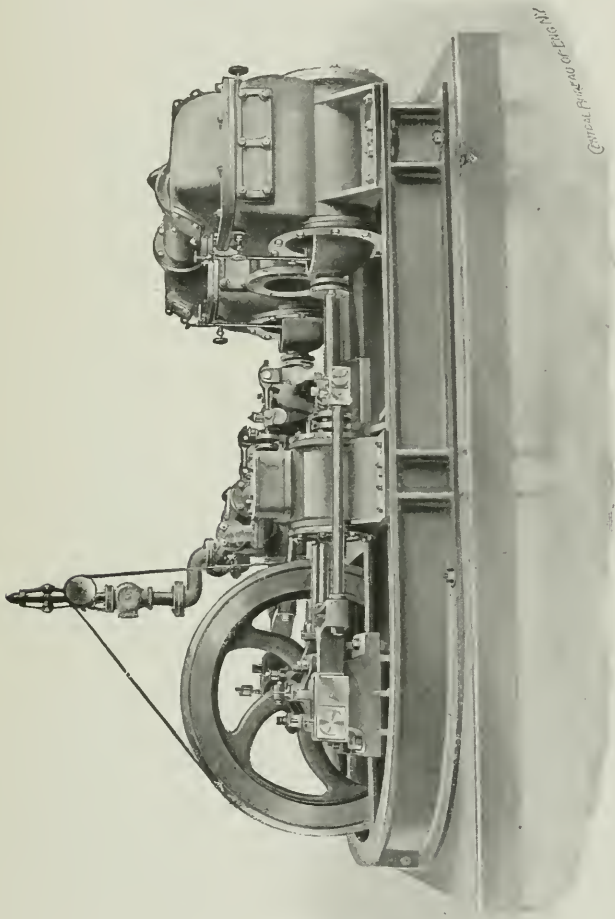


FIG. 17.—THE BLAKE DUPLEX FLY-WHEEL VACUUM PUMP.
For sugar pans and other evaporating purposes.

containing the germ of decomposition, is thus drawn out of the eggs, and carbonic acid gas is forced into the receiver to take the place of it. A variation of this idea is to introduce into the receiver melted paraffine, which fills the pores of the shells.

Eggs are canned by the vacuum process, being heated somewhat to preserve them, but the temperature to which they are raised cannot be high, for the white hardens at 140° F.

There are numerous patents for preserving foods with the aid of the vacuum. One idea is to extract the air contained in the meat, fish, and fruit, which are to be impregnated thereupon with a solution of gelatine. This being accomplished, the meat is to be taken and dipped into a solution of gelatine, sugar, and gum, so as to give it a coating on the outside. Thus it will keep for an indefinite period.

Vacuum processes are to-day largely and successfully employed in the salting and pickling of meats and vegetables. They are shut up in chambers from which the air is withdrawn, and brine is then forced in under pressure. The meat is sometimes stuck full of tubular perforated skewers, to permit the gases to escape and to admit the brine to all parts of the substance treated. Another method adopted is to withdraw the brine with the air pump and force smoke into the meat, which is thus smoked as well as salted. On this idea there is an improvement, which consists in utilizing a smoked brine. This is prepared by withdrawing the air from a tank containing the brine and forcing the smoke into it under pressure. Then the smoked brine is applied to the meat.

Methods are used on a considerable commercial scale for preserving meats and vegetables by withdrawing the air from them and substituting various gases, such as nitrogen and carbonic acid gas. Argon has not been suggested for the purpose as yet, but before long it will be, doubtless. In 1853 Henry Hunt took out the first patent for employing the vacuum in canning fruit products, such as would suffer injury from heating. His idea was to exhaust the air from the cans in order that no germs of putrefaction might remain. A singular adaptation of the same notion is credited to N. Raymer, of New Sterling, N. C., who invented a fruit-jar stopper with a short metal tube attached to it. The housewife, when she has closed

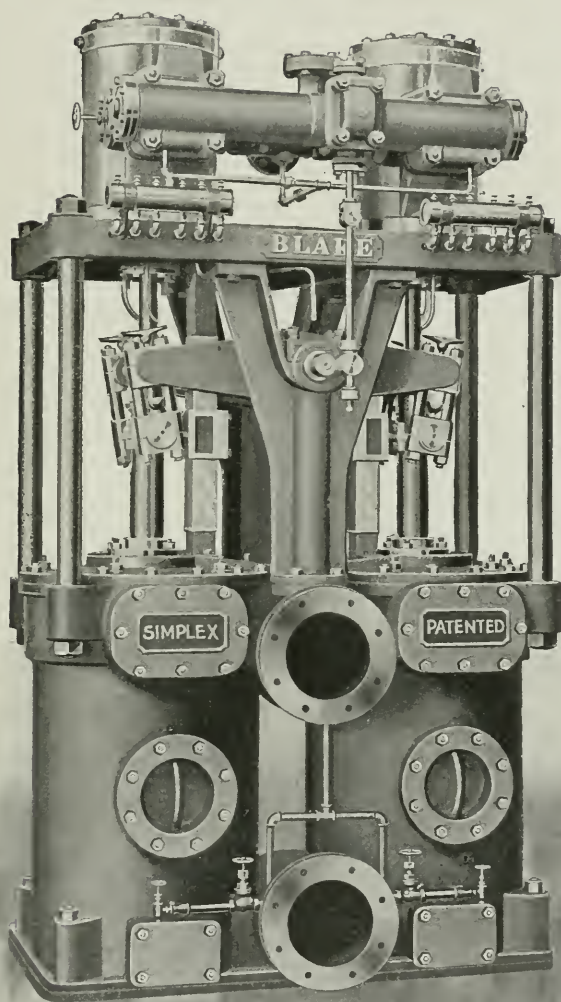


FIG. 18.—THE VERTICAL TWIN AIR PUMP.

Blake pattern for marine service. Single acting beam. G. F. Blake Mfg. Co., N. Y. City.

a filled jar of fruit with such a stopper, has only to draw a partial vacuum by applying a small pump to the tube, and pinch it with pliers, fusing the end with a hot iron to make it air-tight.

The evaporation of fruits and vegetables is a most important industry, and owes its finest output to the vacuum process.

The vast sugar-refining interests of the world are dependent upon the vacuum process for success in the quality of this, the sweetest element of domestic use.

The condensation and preservation of milk has become a large industry in Europe and the United States, and its perfection is greatly due to the vacuum process of evaporation.

One of the most useful applications of the vacuum has been for the preservation of wood. Scores of patents in this line have been granted. So far back as the year 1837 August Gotthilff, of New York, secured exclusive rights in a process for "protecting timber from destruction by worms, dry rot, and other causes of spontaneous decay." His idea was to exhaust the air from the wood and fill up the pores with coal tar and turpentine. In this direction a great industry has since grown up. Piles and railway timbers are impregnated with preservative substances; while metallic solutions are employed by the vacuum process to defend our wooden ships against the depredations of the devouring shipworm or teredo.

Wood is artificially colored by using the vacuum to withdraw its fluid juices, the place of which is filled with solutions containing pigments. In this manner ordinary pine may be beautifully stained and made to serve as a substitute for rare and costly wood. Lumber is seasoned offhand by exhausting the air from it, and then forcing dry air through the pores to carry off the moisture. Wood is hardened for all sorts of purposes, from bridge-making to wagon-making, by a vacuum and pressure process called "vulcanizing."

The variety of purposes to which a vacuum may be applied seems almost endless, and again we continue the enumeration

of lifting of acids and other fluids, exhaust filters, the transfer of sewage from cesspools to closed tanks on wheels for removal, by the vacuum process.

The operation of the pneumatic tube system for cash, telegraph, and postal service has become a most important item for the rapid transportation of mail matter.

A system of transmitting power to small uses by a vacuum pipe system was tried in Paris, France; but was discontinued or changed to the compressed-air system. The great forte in the usefulness of the vacuum has been found in the low-pressure system of steam power, which owes to the vacuum the immense development in the steam motive power of the present time. Our immense steam marine owes its wonderful economy of one pound of coal per hour per horse-power to compounding with triple and quadruple effect derived from the ultimate vacuum. The manufacture of ice by the vacuum process has been accomplished, and rooms have been cooled by air circulation around chambers of ice frozen by a vacuum process.

DRYING IN VACUO.

A vast saving in the economic values of many by-products, consisting of wet grains from breweries, distilleries, etc., and of root chips from beet-sugar manufactories, form, in many cases, food-stuff of value; but on account of the great quantity of water they contain, they are subject to rapid destruction by decomposition, and their nutritious qualities, especially, suffer most. The same cause also prohibits their carriage over any great distance. In the case of wet beer grains, for instance, carriage has to be paid for about 75 per cent. of water. Hitherto, therefore, it has been necessary to utilize these by-products on the spot where they are produced, or at least in close proximity thereto, as well as with the least possible delay. The natural consequence is a low price for such products, of which, moreover, the supply is often greater than the demand,

and thus prevents their realizing anything like their market value, particularly during the hot summer months, when plenty of other food-stuff is to be had. The old plan of preserving such perishable substances in pits or silos is only a very rough and poor remedy and does not answer its purpose at all completely; for, notwithstanding all precautions, decomposition sets in, and a loss of as much as 50 per cent in the nutritious qualities is generally sustained, while at the same time the moisture is by no means reduced, and consequently carriage still remains impracticable.

It has long been endeavored to overcome these disadvantages by removing the surplus moisture by air-drying the by-products, so as to allow of storing and transporting them, and at the same time realizing their full market value. The result of such endeavors has been the construction of different kinds of air-drying machines, which has certainly been a step in the right direction, inasmuch as drying is undoubtedly the surest and safest way of preserving perishable substances. The removal of the water overcomes at once the two great obstacles previously encountered. The rapid decomposition ceases, and carriage to a distance becomes practicable, and the reduction in weight is very considerable. The consequence is that by-products, so dried, bring their full market value.

The process of air drying has been no easy task on account of the low temperature required, wherever it is wished that the dried substance should retain its chemical composition unchanged, which in any article of food is a most important point for enabling a profitable result to be obtained. In general two drawbacks have rendered themselves conspicuous in connection with the air-drying machines hitherto in use; either, in order to shorten the drying process as much as possible, and to make it sufficiently economical, too great a heat has been employed, with the unavoidable result of seriously deteriorating the nutritious qualities of the material; or else, when a longer time and a lower temperature have been

employed for drying, the capacity of the ordinary drying machines has been so small that the working expenses have rendered the process unsuccessful commercially.

All the foregoing disadvantages are avoided if the boiling-point of water is lowered, that is, if the evaporation is carried out under a vacuum. This plan is widely known and used for liquids, but not so much so for solid substances. For the latter it has first been successfully applied in practice by the vacuum-drying apparatus, which is designed to evaporate large quantities of water contained in solid substances, in as short a time and at as low a temperature and expense as possible.

This vacuum plan of drying is already in use for various solid substances, and the result has in every case been remarkably satisfactory. Wet grains from a brewery or distillery, containing from 75 to 78 per cent of water, have by this drying process been converted in some localities from a worthless incumbrance into a food-stuff highly valued and sought after. The water is removed by evaporation only, no previous mechanical pressing being resorted to; hence absolutely the whole of the solid matter is retained, of which, in any process of pressing, a large proportion would have been carried off in a dissolved state in the water. The result is a dry food stuff, rich in quality and satisfactory in appearance.

From malt the removal of the moisture which it contains has to be effected very carefully, and required in the old-fashioned kilns as much as forty-eight hours, because the low temperature necessary could be secured only by slow combustion; this method was and always is a risky one. In the first stages of the drying of malt the temperature has to be kept very low; and in a vacuum apparatus, therefore, hot water, of which the temperature is easily regulated by a thermometer, may be used instead of steam as the heating agent at the outset, while at the same time as high a vacuum as possible is created in the drying cylinders by an air pump of special construction.

If all the water were evaporated from the substances to be

dried, the latter would of course be heated up to the same temperature as the heating surface, and would thereby be injured. This was one of the drawbacks connected with former plans of drying; but it does not occur in the regular working of the vacuum apparatus, because such substances as beer grains or distillery grains, oats, barley, fruits, and vegetables, are never completely dried, but are always taken out of the apparatus while still retaining from 7 to 12 per cent of moisture. Even if they contained less, they would rapidly absorb again from the atmosphere such a quantity of moisture as their dry condition in the atmosphere allows.

In the vacuum process, the boiling-point of the water contained in the wet material is brought down as low as 110° F. or 43° C.; the difference between this temperature and that of the heating surfaces is amply sufficient for obtaining good results from the employment of exhaust steam for heating all the surfaces of the vacuum cylinder. Under atmospheric pressure this difference of temperature would not exist; and to the same cause is also due the short time occupied in drying, notwithstanding the low temperature employed. The water contained in the solid substance to be dried evaporates as soon as the latter is heated to about 110° F., and as long as there is any moisture to be removed the solid substance is not heated above this temperature. The dried product, therefore, remains perfectly unaltered in every respect, and is not in the least impaired in its chemical composition and nutritious properties by the drying process.

THE VACUUM IN SALT-MAKING.

The manufacture of salt by the vacuum process is becoming an important item in the industrial economy of the times, and is now carried on in Austria, England, and the United States. We illustrate, Fig. 19, the initial evaporating section of a triple effect system of Dr. S. Pick, of Szczakowa, Austria,

which is in section of the first effect and almost self-explanatory. The three pans are set side by side, as in a triple sugar apparatus, and the terminal connected with the condenser and air pump.

The section shows the boiling chamber *A* (Fig. 19), the heating chamber *B*, the collecting chamber *C*, and the filtering chamber *D*. The three sections are placed side by side a few feet apart, and are connected together by pipes as a triple effect.

The heating chamber *B* of the first section is placed in communication with a steam boiler, or with the exhaust steam from an engine, by means of the pipe *E*. The boiling chamber *A* of the first section is placed in communication with the heating chamber *B* of the second section by means of the pipe *F*, the second boiling chamber *A'* communicating in its turn with the heating chamber *B''* of the third section by the pipe *F'*. This latter section has its boiling chamber placed in communication with a jet condenser and air pump. *G* is the brine inlet pipe to the various sections and is in communication with the brine tanks,

the brine being raised by vacuum and supplied automatically to the several sections. *H* is a pipe for automatically conducting the brine from the filtering chambers, *D*, to the boiling chamber of each section. *J* is a small pipe which connects the boiling chamber of the first and second sections with the condenser, and is used for assisting in maintaining a vacuum in each of those chambers. In like manner *K* is a small pipe for assisting the vacuum in the heating chambers of the second and third sections by clearing them of surplus air (not shown in cut).

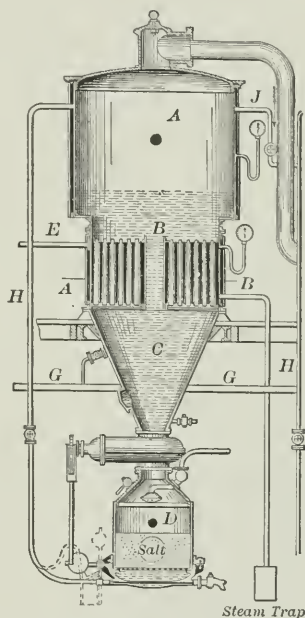


FIG. 19.—VACUUM SALT PAN.

The boiling chamber of each section is simply an iron cylinder, of larger diameter than the heating chamber beneath it. The object of the increased diameter is to enable the chamber to contain a large quantity of brine with a minimum of depth and a maximum of evaporating surface. The usual level of the brine is seen in the section, which is a sectional view of a single apparatus, the second and third sections not being shown. The heating chamber consists of a series of conical tubes of comparatively small diameter surrounding a central tube of larger diameter, as shown in the section. The whole of the tubes are inserted in a tube plate at top and bottom, and inclosed in a cylindrical chamber, into which steam is admitted in the first section by the pipe *E*, and after imparting its heat to the brine it is condensed, and passes away to a steam trap as shown. In the second and third sections the condensed water is drawn off by pumps.

The reason for having the tubes conical is to prevent scaling, or, should scaling take place, that it may be easily removed, the larger diameter of the tubes being at the bottom.

The settling chamber, immediately beneath the heating chamber, serves for collecting the salt as it is precipitated. It settles readily, as no movement takes place in the brine at that point. It is in direct communication with the upper or boiling chamber through the tubes of the heating chamber. This collecting chamber terminates in a sluice valve, and is in this way connected with the vacuum filter beneath it, which forms an important and essential feature of this system. Each filter consists of an upper fixed portion and a lower hinged portion, the filtering medium being attached to the lower portion of the filter at its junction with the upper part. The upper part is fitted with an air inlet cock and a water pipe, ending in a rose for washing the salt if necessary. The lower part of the filter is connected with the boiling chamber by a tube, the lower portion of which, as far up as the valve, is flexible, and yields when the filter is opened, as will be seen from the dotted lines.

The method of operating this system is briefly as follows: Each of the three sections having been charged with brine to the proper level, which is that indicated in the boiling chamber *A*, steam is admitted to the heating chamber of the first section, in which the highest temperature is maintained. The brine in that section becomes quickly heated, and the steam given off from that brine enters the heating chamber of the second section, heating the brine in that section. The steam given off from the brine in the first section, after doing its work in the heating chamber of the second section, condenses and produces a vacuum in the boiling chamber of the first section, which vacuum is aided, if necessary, by opening the valve on the connection with the vacuum pump. The pressure being reduced, the brine in the first chamber enters into violent ebullition at a comparatively low temperature. The same process is repeated in the second section, the steam chamber of the third section acting as a condenser, and producing a vacuum in the boiling chamber of the second section. The steam generated in the third section is drawn off by the vacuum pump and condensed by the jet condenser, not shown. It will be seen that the highest vacuum and the lowest temperature exist in the third section, while the highest temperature and the lowest vacuum occur in the first section. As the salt is precipitated it settles in the collecting chamber, and at stated intervals the sluice valve is opened and the salt and brine are admitted into the filtering chamber. After settling there for a few seconds, the sluice valve is closed and the air cock on the filter is opened. The valve on the ascension pipe *H* is then opened, and in a few seconds more the whole of the brine in which the salt lies as in a bath is automatically transferred to the vacuum chamber, leaving the charge of salt resting on the filtering medium and perfectly free from brine. The valve on the ascension pipe is then closed, the filter opened, and the charge withdrawn. The filter is then closed ready for another charge of salt.

It will be observed that during the operation of letting down the charge of salt and withdrawing it from the vacuum filter, it is not necessary to stop working, the process of evaporation and production being thus rendered simultaneous and continuous, and, above all, automatic. The Miller system of salt-making is similar, only that a pipe leg is extended down from the cone to a tank seal with a hydrostatic height equal to a vacuum, and thus does away with the complication of the Pick system for the delivery of the salt. They are in operation in the salt works in Michigan.

The multiple effect system of evaporation of liquids has so improved of late years that we illustrate in Fig. 20 one of the leading methods of evaporation by forcing the liquids through a tube system divided in small streams in contact with large heating areas, by which the liquid is not long subjected to heat, as in the process of boiling in large volumes.

The illustration (Fig. 20) shows the Varyan multiple effect in section, plan, and elevation. The operation is as follows: The steam, which may be either the exhaust from the engine or live steam direct from the boiler, is led into the cylindrical chamber surrounding the coils in the first effect. The liquid to be concentrated is fed into the first tube of the return bend coils of the first effect in a small but continuous stream, and immediately begins to boil violently, becoming a mass of spray, containing as it rushes along the heated tube a constantly increasing proportion of steam. The inlet end of the coil being closed to the atmosphere, and the steam being continually formed, the contents are propelled through the tubes at a high velocity, finally escaping from the last tube of the coil into the separator. Here the steam or vapor of evaporation, with its entrained liquid, which has been reduced in volume by the evaporation, is discharged with considerable force against the baffle plates, as shown in the figure at the upper left-hand corner, which separates the liquid from the steam, causing the former to fall to the bottom and permitting the latter to pass

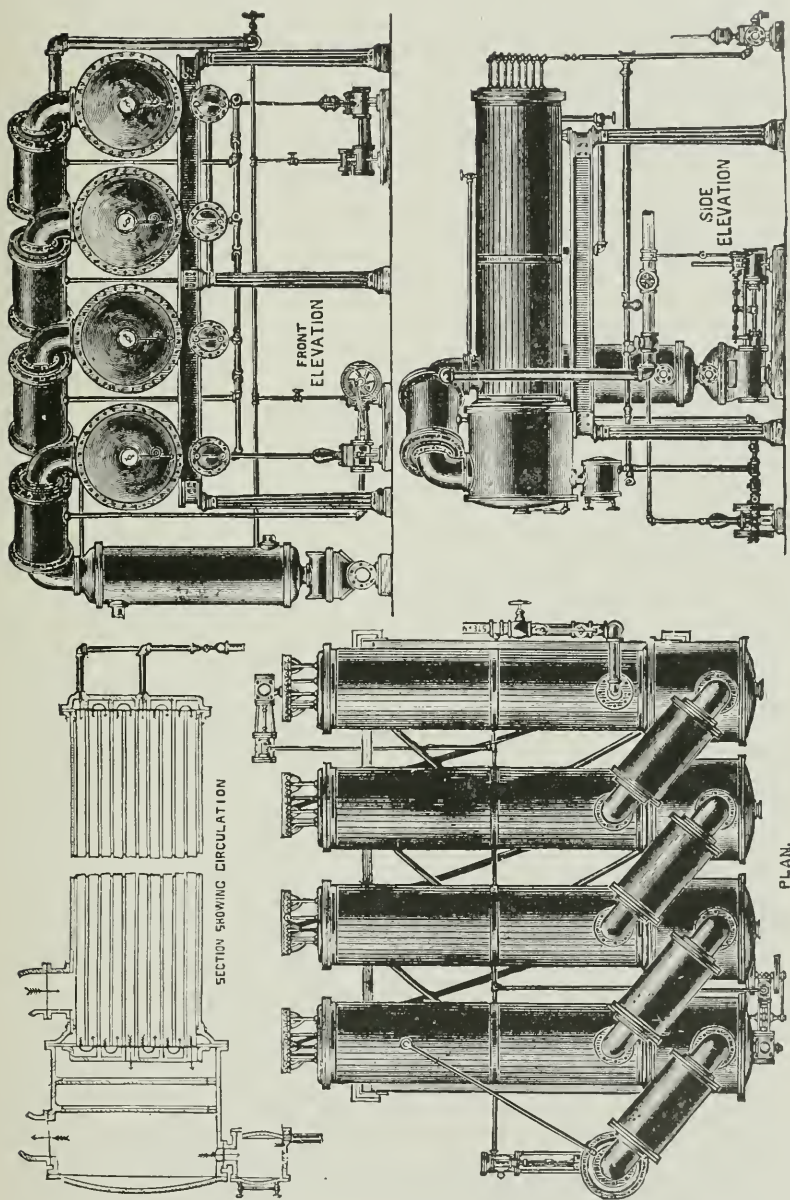


FIG. 20.—YARKYAN EVAPORATING APPARATUS—QUADRUPLE EFFECT, HORIZONTAL TYPE.

off through an ingeniously contrived catch-all, which effectually removes any liquids still remaining into the chamber surrounding the tubes in the second effect, where its heat produces the further evaporation of the liquid. In the second effect the liquid is led from the bottom of the separator of the first effect into the coils, and the same operation takes place as in the first effect, and so on through the entire system, whether triple, quadruple, or more effects are used, the volume of the liquid being constantly reduced in each effect. The steam from the final effect goes to the condenser and the vacuum pump, a high vacuum being thereby maintained in the separating chamber and consequently in the coils; hence the boiling-point of the liquids is at a lower temperature than that of the surrounding steam, and by the condensation of the steam from the previous effect upon the cooler pipes in this effect a vacuum of a less degree is maintained in the next succeeding effect. This relative reduction in pressure, and consequently boiling-temperature, automatically adjusts itself, however many effects are used, thus effecting the boiling of the liquid by the steam produced by its own evaporation in the previous effect. In Fig. 21 is shown a general view of this system of evaporation, with the final condenser and vacuum pump at the right-hand side.

One of the advantages claimed for the system of evaporation of a liquid in the form of a spray subjected to heat under a vacuum is that it receives the heat quickly, and is concentrated in the time of its passage through the tubes, and then relieved of its contact with the high temperature of the first effect and removed to a lower temperature with a higher vacuum, and so on through the whole number of effects.

The spraying is produced by the admission of the liquid at pressure through a small orifice in a large tube, surrounded by the heating steam, evaporation commencing at once, and the steam of the evaporation, being unable to escape except by the path taken by the liquid, by its expansive force blows the small stream, already much broken up, into spray.

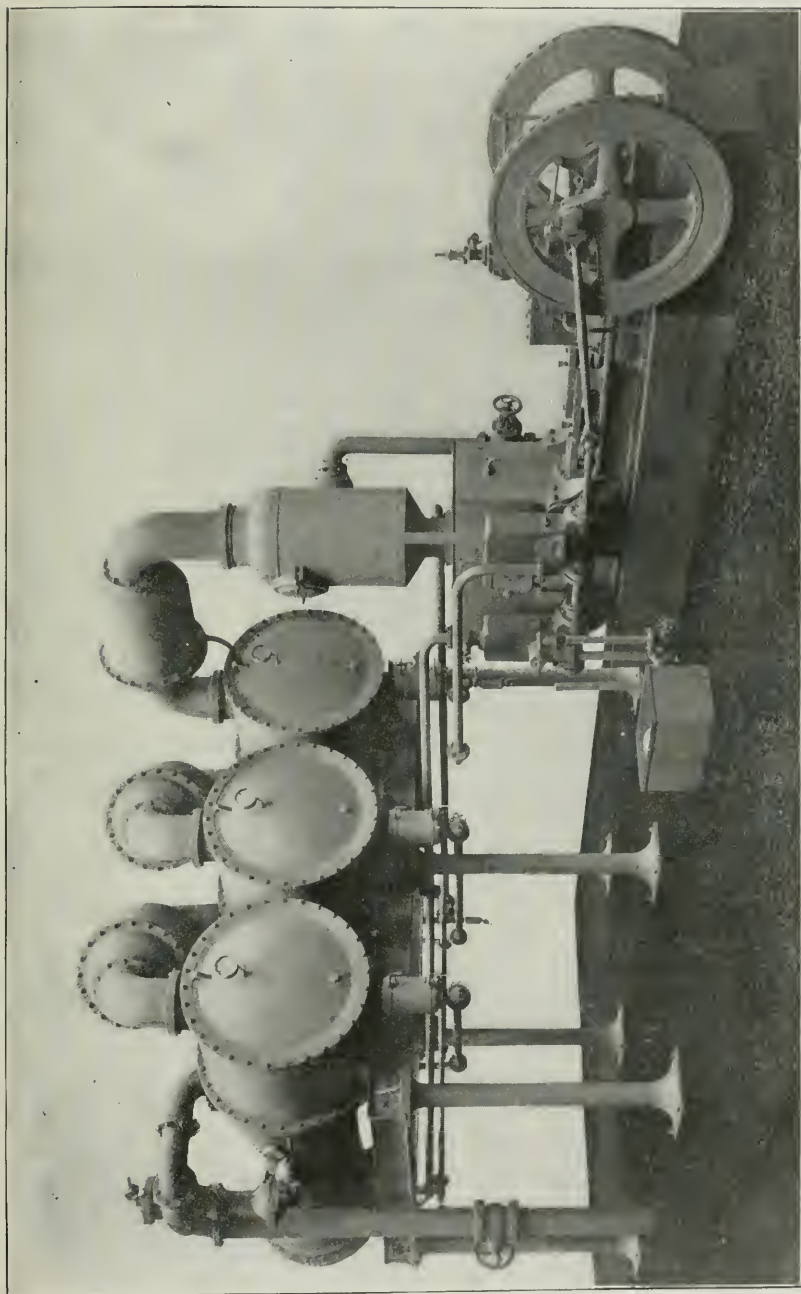


FIG 21.—YARYAN TRIPLE EFFECT EVAPORATOR, HORIZONTAL TYPE.

The rapid motion of the liquid through the tubes of the Yaryan system has the further advantages that, no single particle remaining long in contact with the heated surfaces, in treatment of sugar and other solutions of a delicate nature injury from overheating is avoided, and the scouring action of the combined liquid and steam greatly reduces the liability to form scale.

For the distillation of water for ice-making and for steamers at sea, this principle seems to be the most economical conserver of heat known. In the use of this system, with coal at New York prices, pure distilled water can be produced at a cost of *fifty cents* a thousand gallons, or less. To the manufacturer of ice any process which will give pure distilled water free from oil by use of the exhaust alone of the compressor is a desideratum. Such a process does the Yaryan evaporator afford. The exhaust steam, instead of being condensed to produce the required distilled water, is used only to evaporate fresh water for distillation; hence no trace of oil from the engine can be contained in the distilled water. The condensed exhaust is either used to feed the boilers or goes to waste. No elaborate system of filtering is required, and hence the ice is always clear and transparent.

The address of the Yaryan Company is *Times Building*, New York City.

In Fig. 22 is illustrated a detailed section of the Lillie system of evaporating and concentrating liquids and syrups. It is constructed for triple and quadruple effect by the Sugar Apparatus Manufacturing Company, Philadelphia, Pa. It consists of a stack of slightly inclined evaporating tubes open into the steam chamber at the right and expanded in a thick tube plate, which separates the steam chamber from the evaporating chamber. The other ends of the tubes are closed save a minute air vent in the closed end of each, by which the tube is relieved of air. The liquid or cane-juice is circulated and spread over the tubes of the entire stack by a distributing tube

over each vertical row of evaporating tubes, over which the liquid flows to the bottom, entering a receptacle or well, and into the suction pipe of a centrifugal circulating pump.

The water of condensation in the evaporating tubes flows back and drops to the bottom of the steam chamber into a trap,

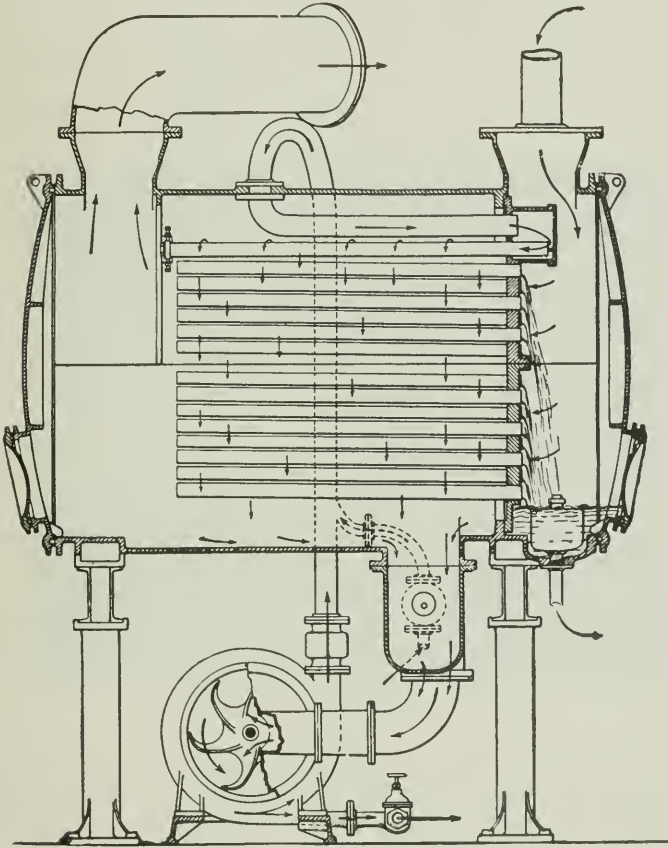


FIG. 22.—LILLIE EVAPORATOR.

and is carried to the next cooler effect, in which chamber it gives up a portion of its heat as vapor to assist in the evaporation of that effect.

In the case of the multiple effect apparatus, the discharge from the bottom of the centrifugal pump is fed to the next effect, with the exception of the last effect, whose discharge

is the concentrated liquor, and goes to the final receptacle. Whether the system of evaporation consists of any number of effects from one to four, the train of operations are solely dependent upon the condenser and vacuum pump at the end of the train for the efficiency of the system.

In Fig. 23 is illustrated a complete setting of the Lillie triple effect sugar train.

In Fig. 24 is represented the elevation of a sugar pan working on the *dry system* of evaporation, in which the water enter-

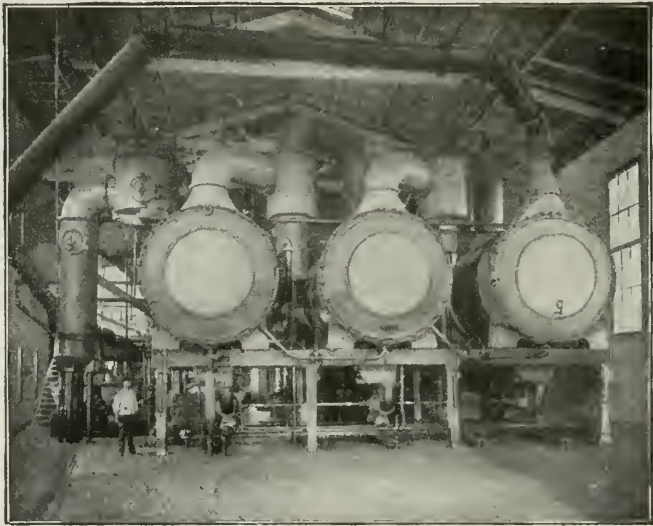


FIG. 23.—THE LILLIE TRIPLE EFFECT.

ing the condenser and the condensed steam, instead of passing through the air pump, passes down a stand-pipe or siphon by gravity to a cistern about 35 feet below the condenser, and which is thereby sealed against atmospheric pressure. In this system the air pumps are only required to keep the system relieved of air and a little moisture or uncondensed vapor. In this type of evaporator a series of copper coils, as shown, five in number, enter the evaporating pan from a header, shown on the outside, and circling around on the inside of the pan until sufficient surface is obtained for the work of evaporation, and

joining to another header, from which the water of condensation from the heating steam is drawn off. In a multiple effect Fig. 24 represents the last pan, and Fig. 25 represents a quad-

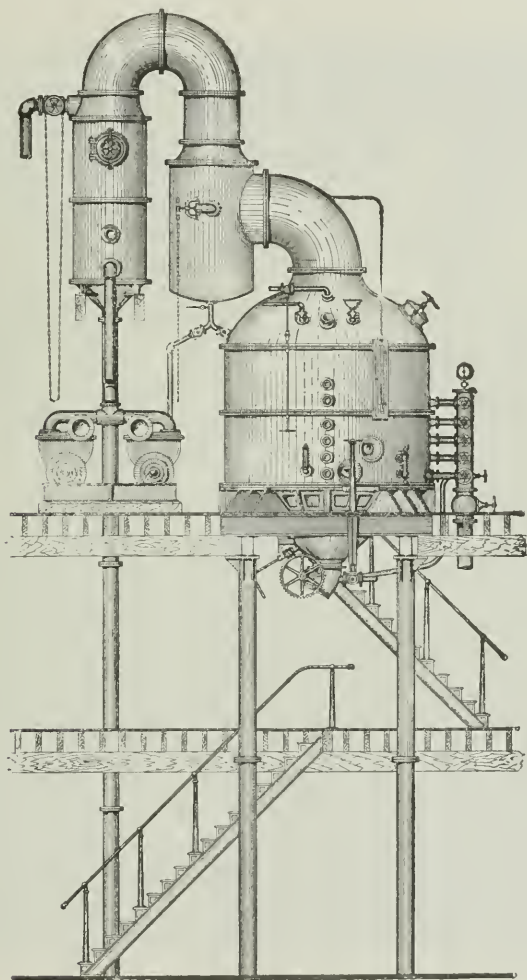


FIG. 24.—ELEVATION OF A SUGAR PAN.

Joseph Oat & Sons, Philadelphia, Pa.

ruple effect, in which the fifth pan shown in the cut is the finishing pan or last receptacle from which the syrup is drawn off to crystallize. Sometimes a surface condenser is used, in which a second pump draws off the water of condensation.

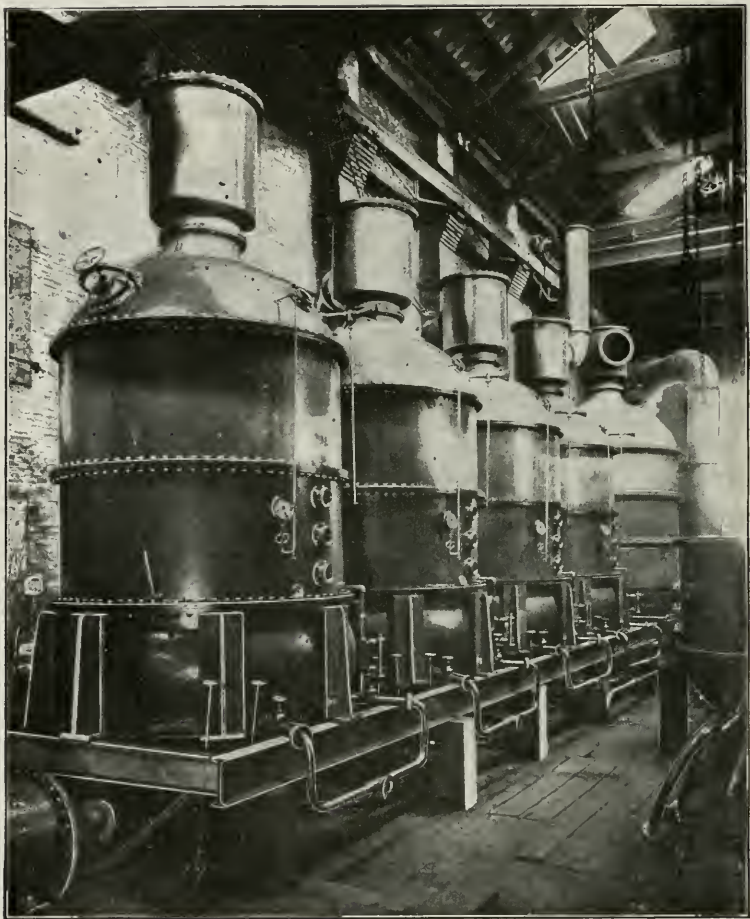


FIG. 25. QUADRUPE EFFECT EVAPORATING APPARATUS.
Joseph Oat & Sons, Philadelphia, Pa.

THE SIPHON AND ITS WORK.

The simple siphon for drawing liquids was known in many forms to the Egyptians generations before the Christian Era, and was much in use among the Romans, to whom was well known the part that a vacuum had in its operation, for it was then used for conveying a water-supply over elevations. The only improvement in modern times has been to supply means for discharging the air while the siphon is running. In Fig. 26 *A* is the siphon, which can be operated over heights of 25 and possibly 30 feet under very favorable conditions as to its

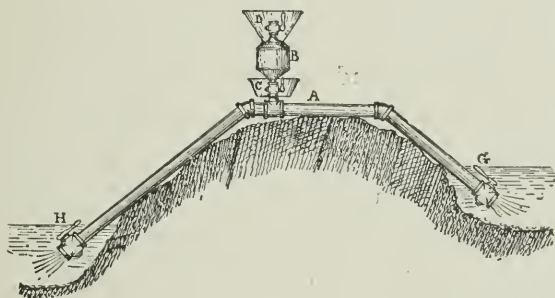


FIG. 26.—THE SIPHON.

length. *H* and *G* are cocks to be closed when first filling the siphon; *B* an air chamber, *C* a water seal for the cock below the air chamber, *D* a funnel for filling and also for sealing the upper cock against air leakage.

The air that accumulates in the chamber *B*, by the operation of the siphon, may be discharged by closing cock *C*, opening cock *D*, and filling the chamber with water. Close *D* and open *C*, when any air below *C* will rise into the chamber, and water will take its place without stopping the running of the siphon.

A PNEUMATIC VACUUM EXCAVATOR.

During the construction of the Tay Bridge considerable difficulty was experienced in sinking the cylinders for the piers, several expedients having been successively tried and aban-

done. At length Mr. Reeves, one of the engineers engaged on that great work, succeeded in devising an excavator on the pneumatic vacuum principle, by means of which the sand was sucked up from within the cylinders and discharged into hoppers, the cylinders following down the displacement of the sand. One of these excavators, or sand pumps, as they are also called, has been completed by A. Wilson & Co., of the Vauxhall Iron Works, England, and has been inspected at work on their premises by a number of engineers. The excavator has been made for the New South Wales government, and will be sent to Sydney, N. S. W., where it will be used in sinking cylinders in connection with the improvements now in progress in the harbor there. The apparatus consists of a pair of cast-iron cylinders 4 feet in diameter, carried on a staging and placed in connection at their tops with an air pump driven by a small steam-engine. The connections are so arranged that the air can be exhausted either from one cylinder singly or both at the same time. The bottoms of the cylinders are connected with a suction tube $3\frac{1}{2}$ inches in diameter, which leads down to the sand. Here again it is so arranged that the cylinders can be worked either singly or in combination by means of self-acting valves. The soil is discharged from each cylinder by a trap-door placed in its front. The engine and air pump are carried on the same framing, and the whole forms a very compact arrangement. In operation, the engine being started, the air is exhausted from one cylinder; the sand and soil rushing up into the vacuum thus created soon fill the cylinder, the fact being indicated by a tell-tale. The connection is then made between the air pump and the second cylinder, and that is similarly filled, during which time the contents of the first cylinder are discharged, and it is ready for the air pump by the time the second cylinder is full, and so the process continues alternately until the desired end has been attained. The excavator worked successfully; a vacuum of 24 inches was maintained during exhaustion, and the cylinders

were rapidly filled with sand and water from a pit, the contents being quickly discharged. Besides the Tay Bridge, this excavator has been advantageously used at the Dundee Esplanade, where a considerable quantity of land was reclaimed by its aid. It also succeeded in pumping the sand from a wreck at Fraserburgh, which led to the recovery of the vessel. In fact, the pneumatic excavator appears to have a wide field of practical application before it.

FLOW OF AIR INTO A VACUUM.

The theoretical velocity of air flowing into a vacuum, if wholly unobstructed, is $\sqrt{2gh}$, or the square root of the sum of twice gravity multiplied by the height of the atmosphere of uniform density due to the height of the barometer, which at 29.921 and 60° F. is 27,816 feet in height and variable with the pressure of the barometer at any place. Twice gravity in middle latitudes is assigned as 64.344, but 64.32 is usually applied to these computations. Then $\sqrt{64.32 \times 27,816} = 1,337.7$, the velocity of the flow of the atmosphere into a vacuum in feet per second, at the above pressure and temperature. This velocity is claimed to be constant at all pressures, so that if a receiver be filled with compressed air at any great pressure, the velocity from an orifice into a *vacuum* would be the same during the time of discharge of the receiver from first to last, although the pressure would be decreasing by the escape of the compressed air. But the quantity of free air issuing per second would not be the same for different pressures in the receiver; it will vary as the density at any moment, multiplied by the coefficient of the orifice. This uniformity of *velocity* of air flowing into a vacuum at all pressures does not hold when the discharge is made into the atmosphere. The height of the atmosphere, due to 1 pound absolute air pressure, is $\frac{27,816}{14.7} = 1,892.2$ feet, and the formula for the flow of air through orifices for differential

pressures may then be used. $\sqrt{2g, h} \times c$ becomes $\sqrt{2g, h - h_1} \times c$ = velocity, in which $h_1 = 1,892.2$ for each absolute pound of back pressure in a partial vacuum chamber, and c a coefficient for the form of the orifice. For example, air at atmospheric pressure flowing into a chamber or tank at about half atmospheric pressure, or, say, 7 pounds absolute pressure, we have $1,892.2 \times 7$ for the atmospheric height, and $\sqrt{2g} \times \sqrt{13,245.4} = 8.02 \times 115.7 = 927.9$, theoretical velocity, and $927.9 \times c = .7 = 649.5$, the actual velocity in feet per second, .7 being the assumed coefficient for the orifice.

Chapter V.

THE FLOW
OF AIR UNDER PRESSURE
FROM ORIFICES
INTO THE ATMOSPHERE

THE FLOW OF AIR UNDER PRESSURE FROM ORIFICES INTO THE ATMOSPHERE.

In the theoretical velocity for the discharge of air into the atmosphere under very low pressures, less than one-quarter of a pound per square inch, as measured by the pressure of water in inches of height, the variation due to difference in air density has been found so small that it has not been considered in the formula which was made the basis for computing Table X., as follows: Theoretical velocity = square root of pressure in inches of water $\times 66.1$; which, multiplied by the coefficient C for a nozzle or a thin plate, gives the tabulated velocities. This table is based on the experiments of Daubuisson and computed for uniform density. The coefficients being for a nozzle of good form .93, and for an orifice in a thin plate .65.

TABLE X.—VELOCITY OF AIR UNDER LOW PRESSURE, IN INCHES OF WATER, WITH EQUIVALENT PRESSURE IN POUNDS PER SQUARE FOOT. TEMPERATURE, 62° F. BAROMETER, 30 INCHES. THEORETICAL AND WITH NOZZLE AND THIN-PLATE ORIFICE. (Box.)

Inches of water	Pounds per square foot.	Theoretical velocity, feet per second.	Nozzle .93 c.	Thin plate .65 c.	Inches of water.	Pounds per square foot.	Theoretical velocity, feet per second.	Nozzle .93 c.	Thin plate .65 c.
0.01	0.052	6.61	6.14	4.29	0.8	4.15	59.1	54.9	38.4
.02	.104	9.35	8.69	6.07	.9	4.67	62.7	58.3	40.7
.04	.208	13.2	12.3	8.58	1.0	5.19	66.1	61.4	42.9
.07	.363	17.4	16.2	11.3	1.5	7.79	80.9	75.2	52.5
.1	.519	20.9	19.4	13.6	2.0	10.38	93.5	86.9	60.7
.2	1.038	29.5	27.4	19.2	2.5	12.98	104.0	96.7	67.6
.3	1.558	36.2	33.6	23.5	3.0	15.58	114.0	106.0	74.1
.4	2.077	41.8	38.8	27.2	3.5	18.18	124.0	115.0	80.6
.45	2.337	44.3	41.2	28.8	4.0	20.77	132.0	123.0	85.8
.5	2.597	46.7	43.4	30.3	4.5	23.37	140.0	130.0	91.0
.6	3.116	51.2	47.6	33.3	5.0	25.97	148.0	138.0	96.2
.7	3.635	55.3	51.4	35.9	6.0	31.16	162.0	151.0	105.3

The coefficient for different forms of orifices and nozzles should be applied to the theoretical velocities in all cases. For

a sharp edge in a thin plate use the coefficient in the table, and with a plate with rounded orifice on the inside a coefficient of from .70 to .75 may be used according to the amount of curvature. With a clean cylindrical ajutage in length three times its diameter a coefficient of from .85 to .90 may be used, if the inner edge is slightly rounded.

Fig. 27 approximates the best form of curve for short nozzles.

The best form of curved taper nozzle will give a coefficient of .96, and a nozzle of the Venturi form, as illustrated in Fig. 8, will still further the velocity to the theoretical figure or more.

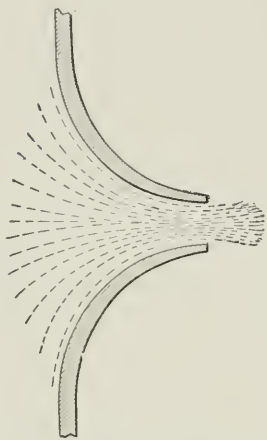


FIG. 27 —AIR JET NOZZLE.

The velocity of air under the higher pressures discharging into the atmosphere has been much the subject of experiment and discussion, and some of our mathematical authors have formulated complex equations that are not satisfactory in meeting reasonable results throughout the scale of pressures. We have adopted the theory of falling bodies and gravity as more applicable to the true conditions of the flow of air from

orifices under pressure and into the atmosphere. For this purpose we use the height of an atmosphere of uniform density equal to the weight or pressure of the atmosphere at sea level with the barometer at 29.921 inches, or a pressure of 14.7 pounds per square inch.

Then the absolute pressure of a free atmosphere, 14.7 pounds per square inch, divided by the assumed or receiver pressure in absolute atmospheres, which, multiplied by the height of the uniform atmosphere (27,816) and the product subtracted from the height (27,816), gives the proportion of the height to which the pressure is due, the square root of which, multiplied by the square root of twice gravity, equals the theoretical velocity in feet per second.

For example, for a pressure of one atmosphere, or 14.7 pounds in receiver, the expression may be $\sqrt{2g} \times \sqrt{27,816 - \frac{14.7}{29.4}}$ or, reducing, $8.02 \times \sqrt{\frac{27,816}{2}}$, and for two atmospheres, $8.02 \times \sqrt{27,816 - \frac{1}{3}}$.

For 50 pounds gauge: Pressure = $3. + \frac{5.9}{14.7}$ atmos. + absolute atmosphere = $\frac{1}{4} + \frac{5.9}{14.7} = \frac{1}{4.405}$ and

$$\sqrt{27,816 - \frac{1}{4.405}} = \sqrt{21,500} \times 8.02 = 1,175 \text{ feet;}$$

or by the decimal method, the ratio of the absolute pressures may be used, viz.: For 50 pounds pressure, $\frac{14.7}{64.7} = .2272$ and

$\sqrt{27,816 - (27,816 \times .2272)} = \sqrt{21,496.3} = 146.61 \times 8.02 = 1,175$ feet theoretical velocity, as before. The theoretical velocity must be multiplied by the coefficient of the orifice for the actual velocity. The form of an air jet nozzle is of great importance for some uses to which the air jet is applied. If a sharp, quick-flowing jet is required, as used for cleansing and dusting, the inside should be smooth and curved from the butt to the tip, of which Fig. 27 represents the type of best form.

For a longer nozzle of best form, the curves may take an elongated shape by extending their length with the same proportional lateral dimensions.

By the experiments of Poncelet, Wantzel, and others, it was found that for pressures above the atmospheric pressure to $\frac{1}{100}$, $\frac{1}{10}$, $\frac{1}{2}$, 1, 5, 10, and 100 atmospheres, the coefficient with a thin plate orifice became .65, .64, .57, .54, .45, .436, and .423 respectively, and with a short tube .834, .82, .71, .67, .53, .51, and .487 respectively.

There is a singular anomaly in the coefficients for a short pipe that does not correspond with the tabulated advance of the theoretical velocities, or of those from an orifice in a thin

plate, as derived from the experiments of Poncelet, Wantzel, St. Venant, and others, which show a maximum velocity from short pipes at a pressure of 50 atmospheres.

From these considerations the following Table XI. of theoretical velocities, with coefficients and actual velocities from the orifices of thin plates and short pipes, has been computed:

TABLE XI.—VELOCITY OF COMPRESSED AIR, THEORETICAL AND FROM ORIFICES IN A THIN PLATE AND FROM SHORT PIPES OF A LENGTH OF THREE TIMES THEIR DIAMETERS. THE COEFFICIENTS OF CONTRACTION DECREASE WITH THE INCREASE IN PRESSURE AND ARE DERIVED FROM THE EXPERIMENTS OF PONCELET AND OTHERS.

Pressure in atmos- pheres.	Pressure, inches of mercury.	Pounds per square inch.	Theo- retical velocity, feet per second.	ORIFICE IN THIN PLATE.		SHORT PIPE.	
				Coefficient of contrac- tion.	Actual velocity, feet per second.	Coefficient of contrac- tion.	Actual velocity, feet per second
0.01	0.3	0.147	94.4	0.65	61.4	0.834	87.7
.066	2.1	1.	246.	.643	158.	.825	203.
.10	3.	1.47	209.	.64	191.	.820	245.
.136	4.08	2.	348.	.63	219.	.815	283.
.204	6.12	3.	472.	.62	293.	.795	375.
.272	8.16	4.	493.	.61	301.	.775	382.
.340	10.20	5.	552.	.59	326.	.755	417.
.408	12.24	6.	604.	.58	350.	.733	443.
.50	15.	7.35	673.	.57	384.	.710	478.
.544	16.32	8.	697.	.567	395.	.704	491.
.611	18.34	9.	741.	.563	417.	.694	514.
.680	20.4	10.	780.	.56	437.	.686	535.
.809	24.28	12.	855.	.55	470.	.678	580.
1.	30.	14.7	946.	.54	511.	.670	634.
2.	60.	29.4	1,094.	.50	547.	.600	656.
5.	150.	73.5	1,219.	.45	548.	.540	658.
10.	300.	147.	1,275.	.436	556.	.520	663.
20.	600.	294.	1,304.	.432	563.	.507	661.
40.	1,200.	588.	1,323.	.428	566.	.498	659.
100.	3,000.	1,470.	1,331.	.423	563.	.487	648.
200.	6,000.	2,940.	1,334.	.418	558.	.476	635.

TABLE XII.—FLOW OF AIR THROUGH AN ORIFICE, IN CUBIC FEET OF FREE AIR PER MINUTE. FLOWING FROM A ROUND HOLE IN RECEIVER INTO THE ATMOSPHERE. (William Cox.)

Diameter of orifice.	GAUGE PRESSURE.						
	2 lbs.	5 lbs.	10 lbs.	15 lbs.	20 lbs.	25 lbs.	30 lbs.
Inch.							
1-64	.038	.0597	.0842	.103	.119	.133	.156
1-32	.153	.242	.342	.418	.485	.541	.632
1-16	.647	.965	1.36	1.67	1.93	2.16	2.52
1/8	2.435	3.86	5.45	6.65	7.7	8.6	10.
1/4	9.74	15.40	21.8	26.70	30.8	34.5	40.

TABLE XII. (Continued).

Diameter of orifice.	GAUGE PRESSURE.						
	2 lbs.	5 lbs.	10 lbs.	15 lbs.	20 lbs.	25 lbs.	30 lbs.
Inch.							
$\frac{3}{8}$	21.95	34.60	49.	60.	69.	77.	90.
$\frac{1}{2}$	39.	61.60	87.	107.	123.	138.	161.
$\frac{5}{8}$	61.	96.50	136.	167.	193.	216.	252.
$\frac{3}{4}$	87.60	133.	196.	240.	277.	310.	362.
$\frac{7}{8}$	119.50	189.	267.	326.	378.	422.	493.
1	156.	247.	350.	427.	494.	550.	645.
$1\frac{1}{4}$	242.	384.	543.	665.	770.	860.	1,000.
$1\frac{1}{2}$	350.	550.	780.	960.			
2	625.	985.					

Diameter of orifice.	GAUGE PRESSURE.									
	35 lbs.	40 lbs.	45 lbs.	50 lbs.	60 lbs.	70 lbs.	80 lbs.	90 lbs.	100 lbs.	125 lbs.
Inch.										
1-64	.173	.19	.208	.225	.26	.295	.33	.364	.40	.486
1-32	.71	.77	.843	.914	1.05	1.19	1.33	1.47	1.61	1.97
1-16	2.80	3.07	3.36	3.64	4.2	4.76	5.32	5.87	6.45	7.85
$\frac{1}{8}$	11.2	12.27	13.4	14.50	16.8	19.	21.2	23.50	25.8	31.4
$\frac{1}{4}$	44.7	49.09	53.8	58.2	67.	76.	85.	94.	103.	125.
$\frac{3}{8}$	100	110.45	121.	130.	151.	171.	191.	211.	231.	282.
$\frac{1}{2}$	179.	196.35	215.	232.	268.	304.	340.	376.	412.	502.
$\frac{5}{8}$	280.	306.80	336.	364.	420.	476.	532.	587.	645.	785.
$\frac{3}{4}$	400.	441.79	482.	522.	604.	685.	765.	843.	925.	
$\frac{7}{8}$	550.	601.32	648.	710.	822.	930.	1,004.			
1	715.	785.40	860.	930.						

Chapter VI.

THE POWER OF THE
WIND

THE POWER OF THE WIND.

THE power of the wind to lift bodies is well exemplified in the kite, and one of its most successful types is the box or Hargrave form, as illustrated in Fig. 28. The dimensions are given in the cut, the rear box being the same width as the forward one. The fore-and-aft sticks c, c may be made of tough pine or white wood $\frac{5}{8}$ inch square; the cross-pieces d, d, d, d , and the vertical pieces should be of the same width, but quite thin; $\frac{1}{4}$ inch for the sides and $\frac{3}{8}$ inch for the cross-pieces. The diagonal braces e, e, e, e , should be of fine, strong fishline, twine, or, better, fine steel wire, for least resistance to the wind; all the corners should be tightly wound with fine strong twine and the fore-and-aft sections covered with fine glazed muslin sewed to the frame.

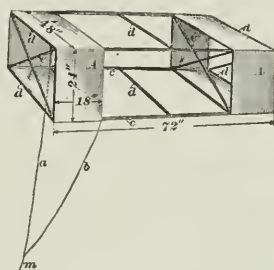


FIG. 28.—THE BOX KITE.

The bridle, a, b , should be double and 6 feet long, fastened to the fore-and-aft stick, at or near the rear side of the front section, and slightly adjustable for balancing the kite by trial.

The bird form of kite, as used for centuries by the Chinese, failed to impress its self-sustaining principles upon the Western world until recent years, when tailless kites came into use and the box form became a useful aerial carrier of meteorological recording instruments. In the cut Fig. 28 is figured the dimensions of a 6-foot box kite, the lifting power of which for a 5-degree angle with the horizontal course of the wind is about three-tenths of a pound per square foot of the surface of the top and bottom members, in a 35-mile wind at the level of the kite, or for the 24 square feet about 7 pounds. The pull of the kite

may be considerable more for friction and the resistance of the frame.

The first form of adjustable tailless kite was the keel kite, which is simply a diamond-shaped Eddy or Malay kite fitted with a fin or keel extending the entire length of the central stick. The width of the keel is about one-third of the greatest width

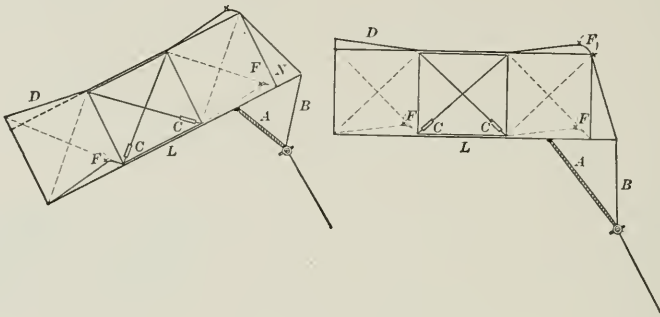


FIG. 29.—HARGRAVE KITE.

of the kite. The bridle is attached in the same manner as that of the Eddy kite, but the end secured to the tail of the kite is elastic, so that in a strong wind it stretches, allowing the kite to assume a smaller angle of incidence to the wind, the pressure of which upon the surface of the kite becomes relatively less. Kites of this pattern usually fly well, but are very liable to become distorted; and when driven to one side by sudden shifts of wind, they recover their normal position less rapidly than other kites. The Hargrave kite is the most stable of those in use.

The addition of the elastic bridle, previously tried on the Eddy and keel kites, effected a marked improvement. Usually the pull exerted upon the flying line by a rigid Hargrave kite without an elastic bridle is extremely variable and jerky, hence destructive alike to line and kite frame and to instruments carried by the kite. The elastic bridle allows the kite to yield slightly to gusty winds, and the records of instruments carried by the kites are as steady as are those made by instruments resting on the ground. This bridle has been modified and improved from time to time, and by its use the pull upon the

line is under absolute control. The elastic may be adjusted so that the pull never exceeds a certain maximum amount. The action of the bridle is shown in Fig. 29 and the method of adjusting in the two positions. The elastic portion of the bridle is shown at *A*, while *B* represents the rigid portion. In light winds the elastic alone receives the strain, as shown in the left-hand diagram, but in strong winds the elastic stretches until part of the strain comes on the rigid cord *B*, which is secured to the front of the kite. The angle of incidence is then very much less, and the effective pressure of the wind relatively diminished.

In Fig. 30 is shown an adjustable bridle clip, made of light metal, with small rollers. The elastic portion of the bridle should be made strong enough to allow the kite to exert a pull of one pound per square foot of lifting surface, or say 24 pounds for a kite of the dimensions of Fig. 28. These kites have been used in a 40 to 50 mile wind with safety when properly constructed for the increased pressure.

Much time has been spent in efforts to improve the efficiency of the kites. All the sticks, wires, etc., of which the frames are constructed are so shaped or arranged as to offer the least possible resistance to the air, and the cloth covers are thinly coated with paraffine and ironed, so that a comparatively smooth and impervious surface is obtained. It was found that increasing the width of the rear cell of the kite caused it to fly at a higher angle; but since the pressure of the wind is much less on the rear than on the front cell, the increased weight rendered the kite less effective in light winds. When the incidence of plane-surfaced kites is small, as it is when the elastic bridle is employed and the kite flown in high winds, the wind pressure upon the edges of the kite drive it backward and downward; and while such kites fly safely in and are not injured by higher velocities, the angular

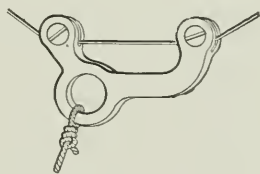


FIG. 30.—BRIDLE CLIP.

altitude reached is so low that very little is gained in attempts to fly them in wind velocities exceeding 40 miles an hour.

Experiments made to find the greatest efficiency of the box kite has shown considerable gain by curving the front edges of the supporting surfaces upward, as shown in the diagrams in Fig. 29. They should be made rigid by bent wood strips.

Steel piano wire is used for the larger-sized kites (No. 14), which weighs about 15 pounds per mile, and should be wound on a strong hardwood drum. It will stand a working pull of 100 pounds. With larger size kites, say of 50 square feet of lifting surface, meteorological recording instruments have been carried to a height of 12,000 feet.

THE WINDMILL AND ITS WORK.

The velocity and force of the wind for creating power was one among the earliest efforts of mankind for obtaining work from the elements of nature.

Without going into details of the tedious progress and development of wind power through the slow march of improvement in windmill construction during the many centuries of their use as a prime mover, the final outcome for efficiency seems to have culminated of late years in the solid annular slatted form, as shown in Fig. 31, or the segmental slatted form, which reefs to the wind for regulating speed.

The American type, or annular sail wind motor, which prevails all over Canada and the United States, is now being largely introduced into Europe, the Oriental and South American countries. In this type, of which there are no less than twelve varieties, comprising a display of great ingenuity in the scheming of their gear, the sail surface is an annulus or broad ring, formed of radial slats. Each slat, of which there are, perhaps, fifty, is a small sail in itself, and is, in most cases, set in its frame at a fixed angle to the plane of motion, the effective wind pressure being automatically varied by making the wind

wheel slew out of, or away from, the wind, so that its disk becomes more and more oblique to the direction of the wind as the pressure increases, thus foreshortening the wheel to the wind. This form has a single vane or rudder parallel to the axis, and carried on an arm springing from one side of the gear frame. This rudder acts against the resistance of a weighted lever, which slews the wheel back into the wind again when the pressure subsides to the normal. This variety is called the "solid wind wheel," to distinguish it from those forms which have sail reefing mechanism. Of the latter, one form in particular, which seems to meet with most favor, merits description, if only on account of its curious and original reefing mechanism.

In the type referred to, the annulus is made up of six, eight, or more segmental frames, each carrying a number of fixed vanes and pivoted on axes which are tangential to a circle described on the wheel face. This wheel is reefed, both automatically and by hand, by causing the sail frames to turn on their axes, so that, when fully reefed, the frames assume a position parallel to the main axle, and are then quite ineffective, the mill being thereby stopped. Intermediate positions, of course, place the vane frames more or less obliquely to the wind by means of a large rudder in the wake of it. In some cases the reefing gear is actuated by a centrifugal governor. This mill, when seen at rest with the sails fully reefed, presents a very wreckish and generally startling appearance. It is strongly suggestive of a large umbrella which has had its ribs unshipped and has otherwise come to grief in a gale of wind. But it is a most efficient conserver of wind power.

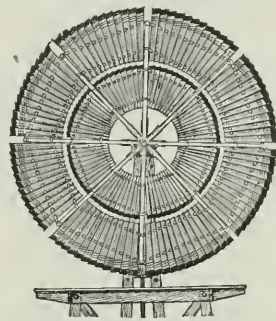


FIG. 31.—THE MODERN WIND-MILL.

The velocity of the periphery of a windmill, constructed as in Fig. 31, should be from one and a half to twice the velocity

of the wind for best effect, and to obtain this relation the angle of the slats at the periphery should be set at an angle of 18° from the plane of the wheel's motion, and at $\frac{2}{7}$ of the radius of the mill the angle should be 34° , the slats having a gradual twist to meet the requirement of the angles. With about these angles the best mills are now built in sizes from $8\frac{1}{2}$ to 30 feet in diameter.

The actual power of these mills as taken from the shaft gear is: Area in square feet of the slats in the plane of revolution multiplied by the cube of the velocity of the wind in feet per second equals the horse-power.

The average velocity of the wind in a large portion of the United States, and for the lowest force that will do effective work with a windmill, is 8 miles per hour for from 5,000 to 6,000 hours in a year, and an average of 16 miles per hour may be expected for 3,000 hours per year; so that for a power that does not require daily attention and can be utilized for twenty-four hours of the day, it is the cheapest for all uses within its sphere of action. For pumping water for storage for all uses, there is no more economical prime mover. In the larger sizes, of 50 and 60 feet diameter, wind power is doing excellent work in our Western States for milling, and in all sizes is largely extending its usefulness in irrigation. The following table gives the sizes of windmills in common use, their power and capacity for pumping water with an average of a 16-mile wind for 8 hours per day:

TABLE XIII.—THE WINDMILL AND ITS WORK.

Diameter of mill.	Horse-power from shaft.	Horse-power in water pumped.	Gallons of water 15 feet high per hour.	Irrigation in acres, column 4.	Gallons of water 25 feet high per hour.	Irrigation in acres, column 6.
$8\frac{1}{2}$ feet.	0.09	0.04	616	0.18	370	0.10
10 "	.16	.12	1,918	.57	1,151	.339
12 "	.25	.21	3,420	1.02	2,036	.60
14 "	.40	.28	4,530	1.37	2,708	.798
16 "	.50	.41	6,460	1.84	3,876	1.142
18 "	.70	.61	9,768	2.83	5,861	1.727
20 "	1.	.79	12,465	3.65	7,479	2.20
25 "	1.50	1.34	21,233	6.27	12,743	3.75
30 "	3.	2.25	31,660	12.88	19,000	7.61

THE WINDMILL FOR ELECTRIC LIGHTING.

One of the many useful applications of wind power is exemplified in the adaptation of the windmill as a prime mover for the generation of electricity, and its storage for lighting and for power purposes at times when the wind is idle.

In Fig. 32 is shown the arrangement for gearing and belting a windmill to a dynamo.

The windmill-driven dynamo charges a storage battery, which has an automatic cut-out when the mill runs too fast or too slow. The mill has also a regulator throwing it out of the direct course of the wind when running too fast, or for stopping the mill.

A windmill 30 feet in diameter, equal to 3-horse-power in a 16-mile wind, running a dynamo, will generate current for 25 in-

candescent lights of 16-candle power each. To run a plant of this kind successfully requires some means of obtaining current when there is no wind, or when the wind is not sufficiently strong for the power required. Some device for keeping the electrical pressure at the required figure should also be employed. For supplying current when the wind is light, or during a calm, it is customary to use a storage-battery. It has also been proposed to run a pump in connection with the wind-

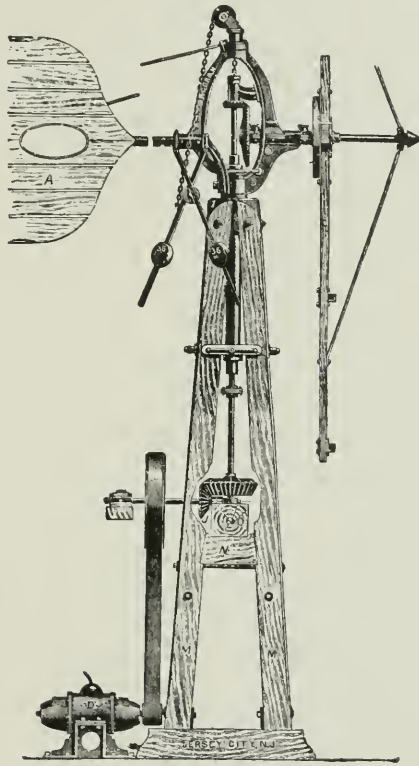


FIG. 32.—ELECTRICITY FROM WIND POWER.

mill and to store water in a tank, or convenient reservoir, using the water to run the dynamo by means of a turbine.

To steady the electrical pressure when the dynamo is run directly from the windmill, as in the figure, three separate methods can be employed. A specially wound dynamo, giving a constant pressure over a wide range of armature speeds, is belted directly to the countershaft; an ordinary dynamo is driven by a pair of cone pulleys placed between it and the countershaft, a governor on the pulleys regulating the speed ratio between the countershaft and the armature: or an automatic regulator is arranged to place storage-cells in circuit with the dynamo as the speed falls, and cut them out as the speed rises.

At times of the day or week when such a mill is not used for the generation of electric current for storage or direct lighting, it will also supply through a pump the water required for a large country house. For the purpose of irrigation alone the windmill is of the greatest advantage to the agricultural interests of the United States, and even in our Eastern States, where irrigation has been heretofore almost totally neglected, it has been found by trials that by the use of a windmill with a small storage capacity for water to meet contingencies the increase in a garden or small-fruit crop alone will amply pay the interest on the plant, and in seasons of severe drought the saving will pay for the plant. These are serious matters for consideration and for the success of our gardeners and small-fruit raisers. Recently a windmill has been erected in Hamburg, Germany, 40 feet in diameter, which furnishes 120 amperes at 160 volts, to charge accumulators for lighting and the operation of small motors. The automatic regulation to meet all contingencies of the wind having been made complete, this system of generating electric power seems assured of success.

AIR COMPRESSION UNDER LOW PRESSURE.

Beyond the power of the ordinary bellows and centrifugal rotary blower, the use of air under slightly higher pressure is often desirable, and for this purpose the double rotary blower is a most useful device for obtaining pressures up to 3 pounds per square inch. Fig. 33 is the form of the Root blower, in which the extended surface of the periphery of the wheels allows them to run loosely in the shell without friction, and with very small loss by air leakage.

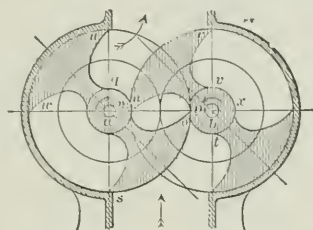


FIG. 33.—ROTARY BLOWER.

This class of blowers, unlike the ordinary fan, can be run at any desired low speed, and its pressure is positive for any measured volume of air under 3 pounds per square inch. Another form of light-pressure air compressor is the compound fan blowers of the Clarke and Hodges type. The one shown in Fig. 34 is a double blower with triple effect. The air is drawn in at each side of the blower and thrown out at increasing pressure successively by the fans on each side, and returned

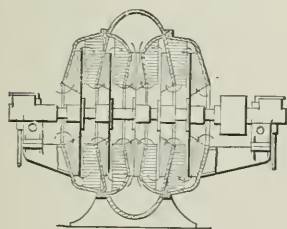


FIG. 34.—TRIPLE BLOWER.

successively by the stationary partitions, with a final discharge at the central annular chamber. With these blowers a pressure of from 6 to 9 pounds per square inch is obtained.

One of the curious properties of air issuing from a bell-shaped nozzle of an air pipe, as illustrated in Fig. 35, is to hold a light ball close to the bell, allowing no more area between the ball and the bell than the area of the smallest diameter of the nozzle. The same effect is also shown with a light flat disk laid on another disk, with an orifice through which air is

blown. Much theorizing has been given to this phenomenal action; but we believe it may be plainly seen that the expanding air in both cases produces a reflex or counter movement of the outside air that neutralizes the pressure beneath the ball and plate.



FIG. 35.—AIR NOZZLE.

The atomizing power of air under the low pressure of a fan or a foot bellows is a most useful appliance in laundries, and there are many examples of the use of air for atomizing fluids in medical and surgical use

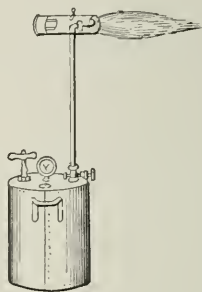


FIG. 36.—GASOLINE TORCH.

and the toilet. The spraying of colors on pottery and coloring dressing material on textile goods is a matter of economy in their manufacture.

Air under low pressure, as derived from the operation of a simple hand pump, is much in use for torch-lights, and by plumbers for melting solder, and by braziers.

The bicycle and vehicle tire pump is too well known to need special description.

The air and gasoline torch, so much used in out-door illumination in street and construction work, is shown in Fig. 36,

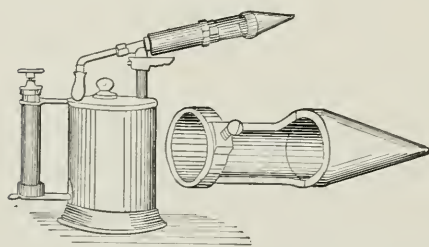


FIG. 37.—GASOLINE SOLDERING COPPER.

and consists of a tank into which a hand-pump is inserted, drawing air from the open top through the piston and discharging it beneath the gasoline, producing a saturated air and vapor gas, which is carried to the

Bunsen burner through the vertical pipe. The additional air for combustion is regulated at the burner, and the vapor at the valve in the pipe near the tank. A gauge shows the pressure.

A small charge of gasoline, say, one pint to one gallon tank, gives best effect, and is safe for all this class of air-gas apparatus. A similar apparatus, Fig. 37, is used for heating soldering coppers made hollow and with a side vent in the copper tip for relieving the flame. The pump forms the handle of the apparatus, so that the copper can be used on the torch apparatus for special work in the open air. It is much in use for making electric wire connections.

The use of air and gasoline vapor for brazing is much in use for small work, and is one of the most convenient means for brazing bicycle parts. In Fig. 38 is illustrated a double-flame brazing apparatus with external air pump and gauge. The handles at the back of the burners regulate the flow of the air-vapor to the Bunsen burners, and a fire-brick or graphite slab forms a back on which the flame impinges and is intensified.

In the four-flame brazier (Fig. 39) the flames impinge on each other, enabling the work to be brazed subject to heat on all sides.

Any desired pressure may be stored in the tanks within a safe factor of strength and the capacity of the hand pump; but the flame pressure must be regulated by the valves for best effect. In this connection a very simple and efficient jet compressor

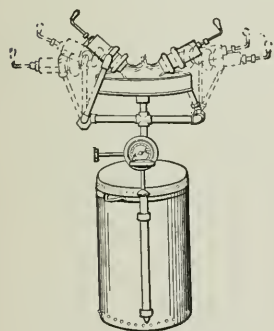


FIG. 39.—FOUR-FLAME BRAZIER.

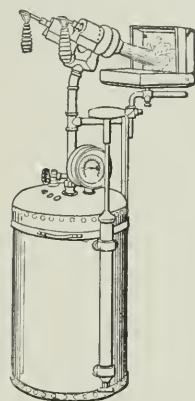


FIG. 38.—AIR GAS BRAZIER.

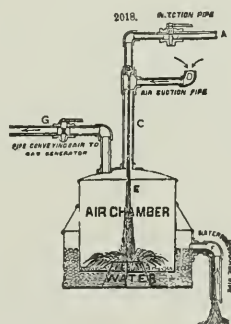


FIG. 40.

may be made for home work in brazing, glass-blowing, etc., with a small apparatus, as shown in Fig. 40, in which a

jet of water from a nozzle falling through the tube *C* draws in air through a side tube and forces it into the air chamber, where the water and air separate under pressure. The water is siphoned off through the water seal at a height due to the required pressure and the force of the jet.

AIR PRESSURE IN GOLD-MINING.

The winnowing of gold-bearing sands for separating the sand and dirt from the particles of gold is in use, and many machines of various forms are in operation in the dry-placer gold-mining districts. An ordinary bellows furnishes an air

blast, which separates the fine sand and dust from the gold on the riffle screens and blows the dust away. A gold winnowing machine is illustrated in Fig. 41.

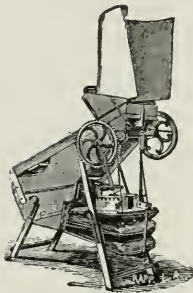


FIG. 41. — DRY-PLACER MINING MACHINE

AIR PRESSURE FOR GRAIN AND VENTILATION.

The winnowing and cleaning of grain is not new, and its aeration in bins and store-houses is one of the modern economies for preserving grain from must, mildew, and heating. Air under the higher pressures is now used to ventilate grain bins 60 feet in height, and thus obviate the necessity of frequent transfer of the grain for its aeration.

The motion of air for ventilation is so well known, and so ably treated in works on ventilation of buildings and mines, that we refer for this subject to such works, of which there are many published.

COMPRESSED AIR FOR BLOWING GLASS.

One of the later applications of compressed air, for the relief of oppressed humanity in regard to health and the elimination of disease caused by the artisan's work, is in the blowing of glass.

The operation of blowing is hard on the workman, not only because of the muscular effort that it imposes on him, but also because of the great volume of air that he has to draw into his lungs within a very short space of time. Such defective conditions are further aggravated by the high temperature and dry atmosphere of the place in which he has to move, and this makes him liable to special affections, such as ulceration of the lips; deglutination and distention of the cheeks, leading to the formation of nacreous patches—an indication of an alteration in the mucous membrane; fistulas of the salivary canal; and a predisposition to emphysema and hernia.

As the blowing is very often performed by young children during their development, the results are still more disastrous.

In order to overcome these inconveniences, a series of apparatus has been invented with a view to securing a substitute for blowing by mouth.

The difficulty in applying blowing apparatus to the glass-worker's tube resides in the fact that the workman is obliged to rotate the latter continuously in order to keep the piece of glass that is being worked in an axis that is sensibly the same as that of the tool that supports it. The position of this tube varies according to the kind of work being done; so, in order to satisfy such different conditions, there have been constructed three types of apparatus to be used: (1) According as the workman is making the glass by revolving it according to a horizontal axis; (2) revolving it according to a vertical axis, the glass being under the tube; or (3) revolving it according to a vertical axis, the glass being above the tube.

This apparatus, moreover, is based upon the use of an air pipe, into which the workman fits his tube, and of an automatically closing cock that he actuates either with his hand or with his foot through the intermedium of levers, so as to produce the expansion that he requires.

For the blowing of glass that is to be rolled a leather pipe is applied to the blowing tube by the boy who helps the work-

man; such is the case in the manufacture of tubes and of cylinders for window glass. In this case the compressed air is distributed on an inclined plane, over which descend the distributing pipes.

The advantages derived from the use of compressed air are of several kinds: It permits, in the manufacture of drinking glasses, to do away entirely with blowing by the mouths of children, and, with very rare exceptions (mostly through inattention of the workman), with blowing by the mouths of adults.

It protects the latter, then, against the special affections that were brought on by the old method of blowing. There being less fatigue for the workman, he produces better work and a greater quantity of it, and the articles are manufactured with greater precision. Finally, the use of this process permits of obtaining, without fatigue to the men, articles of dimensions that have been hitherto unknown, both as regards bulk and other dimensions, such as length and thickness. The limits that may be reached are governed only by the weight of the material operated upon. This process, moreover, is very elastic, since, in consequence of the successive expansions that the workman produces at will, the pressure may ascend from less than an ounce per square inch to several pounds' pressure. In air-pressing glass in moulds it is a great relief to the strain on the lungs, and makes better work, due to greater control of the pressure.

Chapter VII.

ISOTHERMAL COMPRESSION AND EXPANSION OF AIR

ISOTHERMAL COMPRESSION AND EXPANSION OF AIR.

THE free air of the atmosphere in its natural condition may be considered, in all ordinary computations for its use by compression or expansion, as a perfect gas, although there are small differences of effect due to moisture, which modifies the density of air under the process of compression and expansion, and at a certain degree of compression seems to squeeze out, as we may say, the excess of vapor upon cooling to normal temperature in the form of water of condensation. The vapor of water in air that can be held under the various degrees of compression and expansion acts like the properties of air, but is of itself lighter than the other constituents, and contributes to the atmosphere the weight or gravity in proportion to its amount of saturation. Like air itself, and each of its constituents of the so-called permanent gases, moisture is liquefied by pressure and the lowering of temperature.

Dry air being a mixture of several gases, which at ordinary pressures and temperatures are so far from their liquefying point that they are called permanent gases, may, for all practical purposes, be considered as a perfect gas, and be said to obey the same laws. Any gas near its liquefying point is called a vapor, and we may then say that the difference between vapor and gas is one of condition only rather than of composition.

Without entering upon the subject of the molecular constitution of air and its component gases, which has been thoroughly treated in the able works of Carnot, Clausius, Maxwell, Tyndall, and others, we will first consider the *primary law of gases*, which relates to the isothermal compression and expansion of air.

This law of the compression and expansion of air and of other gases *without change of temperature* was first formulated by Boyle, in England, in 1662, and was further established by Mariotte, in France, in 1674. It is called Boyle's law, and relates to the isothermal compression and expansion of air and other gases, and was written: "*When the temperature is kept constant, the volume of a given gas varies inversely as its pressure or elastic force; that is to say, the product of pressure and volume is constant.*"

This has been since found not absolutely true, for in Regnault's experiments in 1847, with a better apparatus, it

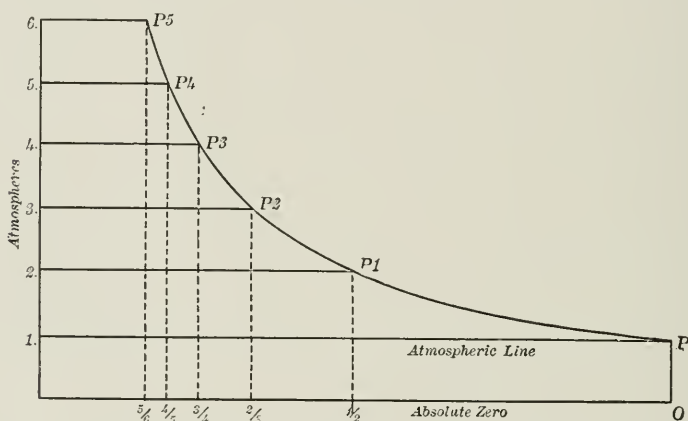


FIG. 42.—ISOTHERMAL DIAGRAM.

was found that the product of volume and pressure at atmospheric pressure (14.7 (V_0 , P_0), divided by the product of volume and pressure at a higher pressure (V_1 , P_1), resulted in a slightly increased volume, which was due to the difference in pressure at constant temperature. This amount was very small, and increasing to but .0063 of the volume at 13 atmospheres, so that for all ordinary computations Boyle and Mariotte's law represents the practical requirements of isothermal compression and expansion. According to this law, the product of the volume (V) and pressure (P) of air or a gas is always a *constant* quantity at the same temperature—that is to say, if you reduce

a given volume of air to half its bulk by external pressure, without change of temperature, then the pressure will be doubled, and by inverting the operation and expanding a given volume to twice its bulk, by external work, without change of temperature, the pressure will be reduced one-half.

A graphic diagram of the pressure curve, due to isothermal compression, may be readily obtained from the algebraic expression of Boyle's law of the product of the pressure and volume. Then $P V = \text{Constant}$.

Let P = the initial pressure of one atmosphere = 14.7 pounds per square inch, and P_1, P_2, P_3, P_4 , the vertical ordinates of the diagram (Fig. 42) representing the fractional parts of compression, or the position of a piston at different points in its traverse of the cylinder, which = 1.

Let $P O$ represent a vertical space equal to one atmosphere (14.7), and each of the five spaces above equal to $P O$, and number them 1, 2, 3, 4, 5, 6 atmospheres. Then the areas contained in the rectangles $P, 1-P_1, 2-P_2, 3-P_3, 4-P_4, 5-P_5, 6$, will be equal to one another, and a curve meeting the points of intersection of the vertical and horizontal ordinates is that of a hyperbola, one of the properties of which is, that the area of the rectangle contained by the horizontal and vertical ordinates from their points of intersection are the same, or equal in area.

Then for any value of the volume V as at a half-stroke of the piston, the pressure P is represented by an inversion of the fraction of the stroke $\frac{2}{1}$, and for two-thirds of a stroke the inversion of the reciprocal of the fraction, or $\frac{3}{1}$, represents the pressure in atmospheres from the absolute zero of pressure, which for gauge pressure requires the atmospheric pressure (14.7) to be deducted. Hence, the inverted reciprocal of any fraction of the travel of the piston in isothermal compression indicates the absolute pressure.

Then for obtaining the proportional part of the stroke of a piston from the terminal, for any desired gauge pressure, divide

the absolute or atmospheric pressure (14.7) by the absolute pressure, plus the gauge pressure, $\frac{P}{P+G} = D$, the distance of the piston from the terminal.

For example: at 75 pounds of gauge pressure, isothermally, the piston would be at $\frac{14.7}{14.7 + 75} = .1638$ of its stroke from the terminal, and this amount will also represent the volume of delivery in parts of the whole stroke, neglecting the clearance space.

In this manner the values in column 5 in Table XVII. were computed, which also shows the relative volumes of compressed air to free air for any pressure from 1 to 3,000 pounds at the normal temperature of 60° F.

In column 3 of Table XVII. is shown the volume of free air to one volume of compressed air at the gauge pressures in column 1, and is computed by dividing 100 by column 7 in Table XVI., or by dividing 1 by column 5 in Table XVI. In column 7, Table XVII., is shown the mean isothermal pressure per full piston stroke, neglecting the clearance, which of itself will slightly lessen the mean pressure.

This was computed by the formula $p \times \frac{1+H}{R} - P = \text{mean pressure}$, in which p = absolute pressure, or the acquired gauge pressure + normal pressure (14.7). R = the ratio of the absolute pressure divided by the normal pressure, and H the hyperbolic logarithm of the ratio R : P = the normal pressure (14.7).

Then, for example, the mean pressure for isothermal compression to 100 pounds gauge pressure will be $14.7 \times \frac{1 + 2.0545}{7.8027} - 14.7 = 30.193$. Ratio $R = \frac{114.7}{14.7} = 7.8027$, the logarithm of which will be found in a table of hyperbolic logarithms, or the common logarithm multiplied by 2.302585.

Chapter VIII.

THERMODYNAMICS

THERMODYNAMICS.

HEAT for a long time was supposed to be a special substance more or less contained in air, the gases, and other substances, which could be taken up or intensified by compression or squeezed out of a body, as air or gas, and the temperature of a body was thought to depend upon the amount of the heat substance present in it. The phenomenon appeared rational, but later investigations pointed to the vibratory molecular theory as being the correct solution of the mystery.

The fact that heat did not increase the weight of bodies was a stumbling-block, and many ingenious theories were adduced to get over the objectionable features of the early theories, yet none proved satisfactory. The relation of heat to and its effect upon the properties of air and its constituents is undoubtedly no longer a generic hypothesis, and whether it be molecular vibration or some other form of energy, it is a fact in regard to its influence and power for changing the condition and constitution of matter. Then heat is a form of energy, free from ponderability and possessing the power of entrance into all substances, and by its action it produces work through the expansion of the substance in which it acts, by virtue of such expansion and the pressure and motion induced thereby.

The accepted law in regard to the expansion and contraction of air and other gases by changes in temperature, or their condition in relation to the absorption and elimination of heat, was formulated by Gay Lussac in France, and Charles in England.

It is called *Gay Lussac's Law*, or the second law of perfect gases, it being understood that a perfect gas is a condition in which the increments of expansion and contraction are exactly

equal throughout the whole range of operation for both volume and temperature. This is not strictly true with any of the so-called permanent gases, for it is now found that all gases are only the vapors of liquids, having a vastly lower temperature degree of liquefaction and refrigeration than water.

With air the law is so nearly true that for all engineering purposes it is accepted in ordinary computation.

Without delving into the relation of heat to other bodies than air and its constituents, we need only formulate the relation of heat to the expansion and contraction of air as composed of its constituents, nitrogen, oxygen, argon, carbon dioxide, and their contained vapor of water.

Heat becomes a means of compression with air when its volume is kept at a constant measure; and heat is made manifest by increase of temperature when a measured volume of air is reduced by external pressure. The terms of both conditions are of equal value: the heat of compression and the cold of expansion are positive and negative equivalents from any initial temperature.

The pressure of air or any of its component gases is exerted in direct proportion to its variation in density, and both pressure and density vary inversely as the volume, supposing the temperature to be kept constant.

At constant volume the density varies as the pressure and also varies as the absolute temperature.

Heat as a mechanical quantity has a measure, which is gauged by its effect in raising one pound of water at its maximum density, through one degree of temperature by the Fahrenheit scale. It is called the *British thermal unit* to distinguish it from the *French caloric*, which is the quantity of heat required to raise 1 kilogramme of water at its maximum density, through one degree Centigrade.

Heat and mechanical energy are mutually convertible, and are measured in foot-pounds of power per heat unit, and this relation is termed the *First Law of Thermodynamics*. The exact

value of its measurement from experiments of Dr. Joule, in England, and of Professor Rowland, in the United States, varies slightly at various temperatures, and as measured by the air or mercurial thermometer, the extremes of which are from 772 to 784 foot-pounds per British thermal unit. The number 778 is probably nearly correct, and will be used in this work. This value is sanctioned by good authority, and, although not Dr. Joule's figures, it is termed *Joule's equivalent* and designated as a mathematical factor by the letter J.

SPECIFIC HEAT OF AIR.

The specific heat of air at constant pressure varies very slightly with the variation of the air temperature ranges in which the experimental data were obtained. The assignment of the average amount of heat required to raise one pound of air through one degree of temperature was found by Regnault to be 0.2375 of a thermal unit, within the range of temperatures in practical use, from 32° to 328° F.

This is accepted as the specific heat of air at *constant pressure* (cp) during which the volume was enlarged during the absorption of heat.

The specific heat of air at *constant volume* has not been found accurately by direct experiment, but has been deduced from the work produced by the expansion of a given volume by the air value of one thermal unit (.2375) at constant pressure. This was found by Joule to be equal to .0686 of a thermal unit, and $.2375 - .0686 = .1689$, the accepted value of the specific heat of air at *constant volume* (cv).

Then using the mechanical equivalent for one thermal unit as a basis (778), the mechanical equivalent for air will be in proportion to its specific heat; then $778 \times .2375 = 184.77$, the mechanical equivalent of one pound of air at *constant pressure* (Mcp) and $778 \times .1689 = 131.6$, the mechanical equivalent of one pound of air at *constant volume* (Mcv).

The weight of one cubic foot of dry air at sea level, barometer 29.921 and 32° F., is 0.080728 lb., and $\frac{1}{.080728} = 12.387$ cubic feet in one pound of air at 32° F.

Then the total pressure of the air at sea level per square foot (P_0) 2116.2, multiplied by the volume of 1 lb. (v_0) 12.387 c. ft., and divided by the absolute temperature from 32° F., 492.66, equals the difference in the specific heats of air in foot-pounds at *constant pressure* and at *constant volume*, viz., $\frac{2116.2 \times 12.387}{492.66} = 53.17$.

Then, as above stated, the mechanical equivalent of one thermal unit per pound of air at *constant pressure* (M_{cp}) = 184.77 ft. lbs. and at *constant volume* (M_{cv}) = ... 131.60 “

Difference $M_{cp} - M_{pv} = (D) = 53.17$ “

53.17 as a ratio will be noted and used in some of the formulas further on.

The specific heat of air has been found by experiments of Professor Linde not only to increase by its temperature density, but also to increase by density from compression. He has computed an interesting table of these values, which we here reproduce:

TABLE XIV.—SPECIFIC HEAT OF AIR AT VARIOUS TEMPERATURES AND PRESSURES.

Temperature, Fahrenheit.	PRESSURE IN ATMOSPHERES AND POUNDS.					
	1 14.7 lbs.	10 147 lbs.	20 294 lbs.	40 588 lbs.	70 1029 lbs.	100 1470 lbs.
212°	.2372	.2389	.2408	.2446	.2512	.2583
32	.2375	.2419	.2465	.2512	.2773	.2986
— 58	.2380	.2455	.2572	.2785	.3319	.4124
— 148	.2389	.2585	.2844	.3697	.3461	
— 238	.2424	.3105	.5048			
— 274	.2467	.4147				

It is observed by inspection of the table that the specific heat of air at constant temperature increases with the pressure, at an increasing ratio at ordinary temperatures, and is over 25 per cent at 32° from 1 to 100 atmospheres, the specific heat at

32° , .2375, being the term in use for air computations. It also increases largely with its density from increase of pressure with decrease of temperature, as well as with decrease of temperature at constant pressure.

ABSOLUTE TEMPERATURE AND ITS ZERO.

The recent experiments of scientists, and especially those who have been operating in the liquefaction of air and other gases, seem to have thrown some doubt upon what has heretofore been conceded as *absolute zero*, and the fact of an absolute zero has been lately ridiculed and stated to be a "thermodynamic heresy," and that the beautiful diagrams drawn from its equations or formulas are misleading.

We take no stock in flimsy denials based on no better foundation than mental doubt. The operations of computation from the adopted facts and formulas work well within the scope of practical engineering, and it is safe to follow them until something better is found that is based upon an equally good foundation.

So that it may be taken for granted that the zero of the scale of temperature by which the various computations in Aerodynamics are made is the lower terminal in the heat scale at which no further division can be made and no further expansion of air or gas can be obtained. It is the equivalent of absolute cold and of absolute vacuum.

The lowest temperature that has as yet been reached experimentally is that of frozen liquid air at a temperature of -404° F. or only 56° above the computed absolute zero.

In order to obtain the starting-point of the absolute scale, a backward process was made, based upon the expansion of air through a measured range of temperature between two fixed points that are well known and reliable in thermometric work.

Regnault found that if a volume of air be kept constant at various initial pressures of from 2.12 pounds absolute to 70.7

pounds absolute, the volume when heated from 32° F. to 212° F. expanded at the lowest initial pressure to 1.36482 and at the highest pressure to 1.37091, a difference of .00609, which was attributed as due to some peculiar property of an imperfect

gas in its variable expansion under different pressures. It may have been from the influence of moisture or the vapor of water so difficult to eliminate from air experiments, and here comes the basis of the so-called "thermodynamic heresies."

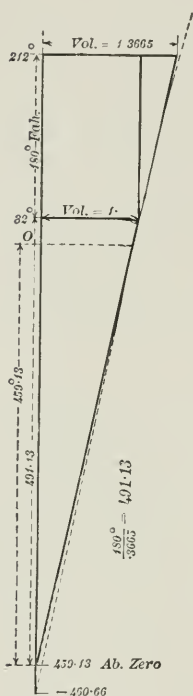


FIG. 43.—SCALE OF ABSOLUTE ZERO.

At atmospheric pressure, however, the expansion from one volume was found to be 1.3665 intermediate between the other determinations, and this rate was adopted for obtaining the ratio of expansion and contraction per degree from the freezing-point of water (32° F.) and its boiling-point (212° F.). These three ratios seem to indicate a curve in the expansion line above and the contraction line below the trial temperatures, which might extend the absolute zero far below the limit as computed from the mean ratio; but as this has not been fully shown experimentally, the adopted ratio seems to answer

all practical purposes within the ordinary limits of engineering work.

By dividing the ratio of expansion by the number of degrees over which it extended, the ratio for each degree was obtained,

viz., $\frac{.3665}{180^\circ} = .00203611$ = the expansion of air by volume for

1° rise in temperature; therefore $\frac{1}{.00203611} = 491.13$, which

represents the number of degrees equivalent to the volume (1) from which the departure for expansion from absolute zero was started; it represents the number of degrees below the freezing-

point (32° F.) at which air ceases to be divisible either in expansion or in temperature; and $491.13 - 32^{\circ} = 459.13$ below zero F. was adopted for the absolute zero for a perfect gas. This value has been much used, but by later experiments of Joule and Thompson, and probably owing to a small variation in the relative value of air expansion throughout the scale of experiment, the absolute zero has been fixed and accepted by good authorities at 492.66° below the melting-point of ice (32° F.) and at 460.66° below zero F., and will be so used in this work.

This assignment of the absolute zero (492.66) makes a slight variation of the ratios used for the computation in the older tables of air compression and expansion, which will then become $\frac{1}{492.66} = 0.00202978$ per degree Fahr. for extreme temperatures; but this need not change the ratios as actually found between 32° and 212° F. (0.00203611) for any range of temperature in ordinary use; except that the expansion of air by heat at very high temperatures may not follow the ratio exactly.

The indications are that there appears to be a slight curve in the expansion line from 32° F. to the absolute zero, which when extended from 212° upward may slightly increase the volume at high temperatures as computed by the ratio.

It may be asked whether it is possible that air or gas when deprived of all sensible heat will cease to occupy space? We answer no! For at this time it is well known that all gases and their compounds, as air, are but vapors of liquids, that liquefy and become frozen into solids before the temperature of absolute zero is reached. Then we must consider that the absolute zero of our ratio scale of atmospheric temperatures is the point of elimination of its values at its lowest degree.

With the ratio of $.00203611$ as the increase per unit degree Fahr. the volume and pressure may be computed for various temperatures for the expansion of the volume of one pound of air expressed in cubic feet, and also for the pressure of a con-

stant volume by change of temperature. In Table XV. are given the volume, pressure, and density of air at various pressures from 0 to 3000° F. It nearly follows the ratio given above within a fraction.

The expressions for the ratio R, for the inner work performed under atmospheric pressure, may be written

$$R = \frac{V_0 P_0}{T} = \frac{V_1 P_1}{T_1} = \frac{V_2 P_2}{T_2}.$$

That is, if we divide the specific volumes, multiplied by their corresponding pressures, by the corresponding absolute temperatures, the quotients are constant and equal to R or 53.17, for 32° F. and for the pressure per square inch the ratio will be $\frac{53.17}{144} = 0.3696$.

Then $\frac{V_0 \times P_0}{T} = R$, and $\frac{V_0 \times P_0}{R} = T$; also $\frac{R \times T}{V_0} = P_0$, and $\frac{R \times T}{P_0} = V_0$.

For example, one pound of air at 32° F. = V_0 or 12.387 cubic feet, P_0 = atmospheric pressure 14.7, and the absolute temperature at 32° is 492.6.

Then $\frac{12.387 \times 14.7}{492.6} = .369648$ = Ratio, and $\frac{12.387 \times 14.7}{.369648} = 492.6$, also $\frac{.369648 \times 492.6}{12.387} = 14.7$, and $\frac{.369648 \times 492.6}{14.7} = 12.387$, following the equations as above written.

In Table XV. the 1st column shows the degrees of temperature from 0° F. to 3000° F. The 2d column shows the volume of 1 pound of air at the different temperatures in the 1st column. The increase in volume is obtained by multiplying the ratio .00203611 by the number of degrees above 32° and by the volume at 32° (12.387), and to the product add the volume 12.387; so that, for example, for the expansion of air from 32° to 340° we have a difference of 308°, and $.00203611 \times 308 \times 12.387 = 7.7681 + 12.387 = 20.155$ cubic feet of air, equal to 1 pound as found in the second column opposite 340° in the 1st

column. The small fractional difference arises from the cutting off of fractions in the terms of the computation.

By using the expression $\frac{v_0 \times t}{T}$ for the volume of one pound of air as expanded by heat, as in column 2, Table XV., the volume $v_0 = 12.387$ at 32° , and at 360° the absolute temperature is $360^\circ + 460.6 = 820.6$, and the absolute temperature below 32° is 492.6 . Then, as by the equation, $\frac{12.387 \times 820.6}{492.6} = 20.63$ cubic feet in the volume at 360° expanded by heat from 32° F., as given in column 2 opposite 360° in column 1.

TABLE XV.—VOLUME, PRESSURE, AND DENSITY OF AIR AT VARIOUS TEMPERATURES. FROM NORMAL VOLUME AND PRESSURE AT 62° F. (Haswell.)

Temperature, Fahrenheit.	Volume of one pound of air at atmospheric pressure, 14.7 pounds.	Absolute pressure of a constant volume by heat.	Weight of one cubic foot of free air at temperatures in column 1.	Temperature, Fahrenheit.	Volume of one pound of air at atmospheric pressure, 14.7 pounds.	Absolute pressure of a constant volume by heat.	Weight of one cubic foot of free air at temperatures in column 1.
	Cube feet.	Lbs. per sq. in.	Lbs.		Cube feet.	Lbs. per sq. in.	Lbs.
0°	11.583	12.96	.086331	360°	20.630	23.080	.048476
32	12.387	13.86	.080728	380	21.131	23.640	.047323
40	12.586	14.08	.079439	400	21.634	24.200	.046223
50	12.840	14.36	.077884	425	22.262	24.900	.044920
62	13.141	14.70	.076097	450	22.890	25.610	.043686
70	13.342	14.92	.074950	475	23.518	26.310	.042520
80	13.593	15.21	.073565	500	24.146	27.010	.041414
90	13.845	15.49	.072230	525	24.775	27.710	.040364
100	14.096	15.77	.070942	550	25.403	28.420	.039365
120	14.592	16.33	.068500	575	26.031	29.120	.038415
140	15.100	16.89	.066221	600	26.659	29.820	.037510
160	15.603	17.50	.064088	650	27.915	31.230	.035822
180	16.106	18.02	.062090	700	29.171	32.635	.034280
200	16.606	18.58	.060210	750	30.428	34.040	.032865
210	16.860	18.86	.059313	800	31.681	35.445	.031561
212	16.910	18.92	.059135	850	32.941	36.850	.030358
220	17.111	19.14	.058442	900	34.197	38.255	.029242
240	17.612	19.70	.056774	950	35.454	39.660	.028206
260	18.116	20.27	.055200	1,000	36.811	41.065	.027241
280	18.621	20.83	.053710	1,500	49.375	55.115	.020295
300	19.121	21.39	.052297	2,000	61.940	69.165	.016172
320	19.624	21.95	.050959	2,500	74.565	83.215	.013441
340	20.126	22.51	.049686	3,000	87.130	97.265	.011499

In column 3 the absolute pressure at constant volume is obtained from the equation $\frac{P \times t}{T} = Pv$, and for the pressure at 360 from a constant volume from 62° F. we have $\frac{14.7 \times 820.6}{522.6}$

= 23.06, and so on for any desired temperature and pressure from the values of absolute pressure and temperature p and t .

The 4th column of Table XV. is the weight of 1 cubic foot of free air at the temperatures in column 1. The expression $\frac{D \times T}{t} = D_1$, in which D is the density of air or the weight of 1 cubic foot at 62° F., T the absolute temperature from 62° , and t the absolute temperature from any required temperature. Then for the density at 360° $\frac{.076097 \times 566.6}{820.6} = .048476$.

For obtaining the volume of expansion for any temperature not found in the table, a proportional interpolation of quantities between the two nearest temperatures in the table will be found approximately near enough for all practical purposes.

For the unit value of pressure, divide the greater value of expansion by the lesser, which gives the ratio due to the lesser pressure; as, for example, the volume of one pound of air at 62° is 13.141, and the volume at 340° is 20.126, and $\frac{20.126}{13.141} = 1.531$, which multiplied by the atmospheric pressure for the lesser volume, $14.7 \times 1.531 = 22.51$, the absolute pressure of a constant volume by an increase in temperature from 62° to 340° F. Its weight per cubic foot is also found by dividing the weight of the lesser volume in column 4, by the ratio as above, 1.531. For the cubic feet of one pound of air at any temperature, the weight of one cubic foot of air at 60° F. multiplied by its absolute temperature, viz., $.076097 \times 522 = 39.7226$, a constant by which the cubic feet of one pound of air at any other temperature may be readily computed. For example, in Table XV. the weight of one cubic foot at 62° F. = .0761 was used, which gives the constant 39.7242. Then the value of one pound in cubic feet at 32° is $\frac{492}{39.7242} = 12.387$, and for 100° F. is $\frac{560}{39.7242} = 14.097$ cubic feet as found in the table.

Another useful constant is derived from the sum of the weight of one cubic foot of air and its absolute temperature,

divided by the absolute atmospheric pressure 14.7. Thus say for 62° F. $.0761 \times 522^\circ = 39.7242$ as before, and $\frac{39.7242}{14.7} = 2.70204$, which may be used for the weight of one cubic foot of air at any pressure and temperature, by multiplying the constant by the absolute pressure and dividing the product by the absolute temperature. Thus, for the weight of one cubic foot of air at sixty pounds pressure and 62° F. temperature we have $\frac{2.70204 \times 74.7}{522} = .3866$ pound.

Chapter IX.

ADIABATIC COMPRESSION AND EXPANSION

ADIABATIC COMPRESSION AND EXPANSION.

HAVING shown the relation of compression and expansion of air as a perfect gas under the isothermic law of Boyle as illustrated in Fig. 42, the action of heat as evolved in compression and eliminated in expansion of air becomes a most important factor in the practical work of compression, transmission, and the utilization of air power.

The adiabatic or isotropic lines or curves representing the moments of pressure due to the generation of heat by compression or the elimination of heat by the expansion of air, may be computed and expressed in diagrammatic form from the formulas representing the varying conditions of increase or decrease of progressive pressure. The theoretical curves as derived from the equations represent the conditions when there is no absorption of heat by the walls of a cylinder in which the operation is taking place. In practice this curve is never produced, but a modified form, lying between the theoretical and the isothermal, is the resultant as produced on an indicator card.

The limiting point of heat by the compression of air is unknown, but is probably at the pressure of liquefaction, which has not yet been found with pressures up to 15,000 pounds per square inch and at temperatures raised in the experimental compressors and receivers. When air is once liquefied by pressure and artificial cold, it has been found to hold its liquid state at about 12,000 pounds pressure per square inch at normal temperature, 60° F.

Cooling from the expansion of compressed air is inversely in the same ratio as from compression; or, the temperature falls by the same scale that it rises.

As we have said above, the heat saturation point is probably at the pressure of liquefaction; so the cold extreme from expan-

sion is probably at the absolute zero of expansion or perfect vacuum; which is now accepted as the zero of absolute temperature, 460.66° below the zero of the Fahrenheit scale.

The difference of temperature by compression for equal increments of pressure is much greater in the lower part of the compression scale than in the upper part; as, for example, the increase of temperature from atmospheric pressure to one pound per square inch is 10° F., while for an increase of one pound pressure from 99 to 100 pounds it is but 2.4° F. The differences of temperature when plotted on a pressure diagram form a parabolic curve from its axis at absolute zero and terminating at infinite pressure and temperature; the conditions within the limits of practice indicate this curve, as also its inverse order in the expansion of compressed air.

Compression to the higher figures is not practicable by one stage compression, for at 1,000 pounds pressure the air rises to a full red heat, 1313° F., and at 2,000 pounds to 1709° F.

This is the theoretical temperature, but as much of the heat in the air would be absorbed by the compressor, it would soon become too hot for economical operation.

The three elements involved in expressing the adiabatic condition of air or a gas are the pressure, volume, and absolute temperature. The quotient is always the same, however the pressure, volume, or temperature may change; given any two of these, the other may be readily determined; for the absolute pressure at constant volume varies with the absolute temperature, $(pv) \propto T$, and the volume at constant pressure also varies with the absolute temperature, $(v)_p \propto T$. Then in the work of air compression pv^{γ} is constant.

Supposing that no attempt whatever is made to keep the air cool, and that the air is to be compressed in a cylinder which will neither take up any of the heat of itself, nor allow any to pass out of the air while it is being compressed; this would be a case of adiabatic compression, and we should find that, when the volume had been reduced to one-half, the pressure would

not be double only, as in the isothermal case, but more than double, because of the heat generated during compression being still in the air; or, what comes to the same thing, when any given pressure is reached there would be a greater volume of air, owing to the heat in it, than had been found when compression up to that same pressure had been isothermal. In making a diagram to show how the pressure varies in such a case, we must take into account not only the reduction of volume, but also the effect of the heat generated while that reduction is being made. The molecular theory helps us to understand

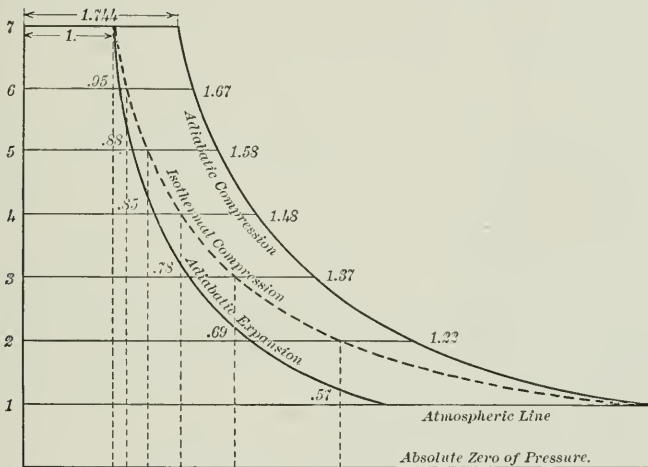


FIG. 44.—ADIABATIC COMPRESSION.

why heat must be generated during both kinds of compression, for as soon as the piston begins to move it increases the energy of molecular vibration in the air contained by the cylinder, and is developed into activity and becomes sensible.

A simple way of making a diagram of adiabatic compression is to draw the isothermal curve first (the dotted line in the figure being the same as in Fig. 42), and then add to it, at various pressures, the extra volume due to the heat which has been generated while compressing up to that point. This extra volume can be found by taking the natural number which corresponds to two-sevenths of the logarithm of the absolute pressure;

the heat curve of adiabatic compression of air, the terms for each increment of compression are equal to the product of the volume and pressure raised to the heat ratio of 1.406, and the expression for each in-

$$\text{crement of pressure will be } pv^{1.406}, = p_1 v_1^{1.406}, = p_2 v_2^{1.406} \text{ or } \frac{v}{v_1} = \frac{p_1}{p},$$

where v is the greater volume and p_1 the greater pressure. By using Napierian or common logarithms, the expression becomes $1.406 \times \log. \frac{v}{v_1} = \log. \frac{p_1}{p}$.

The thermal result of air compression and expansion is shown by the diagram Fig. 45. Both the temperature of the air and its volume are shown at different stages of compression. The simplest application of this diagram is that which gives the gauge pressure represented at

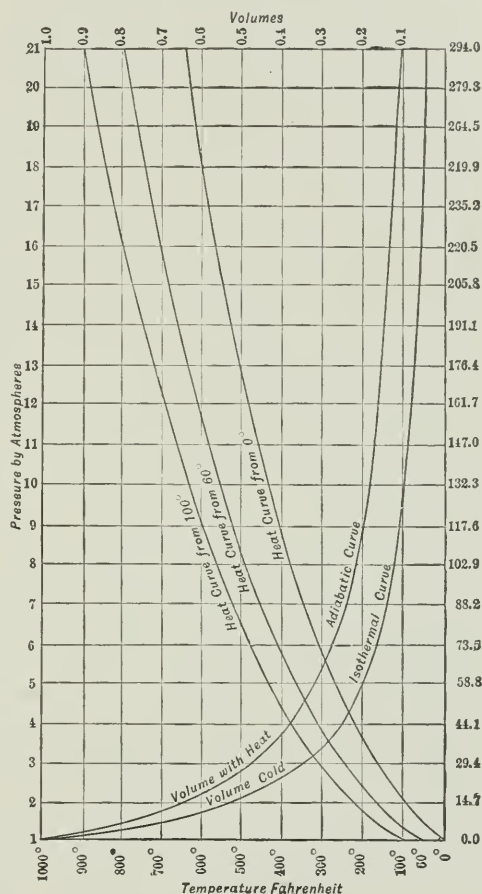


FIG. 45.—ADIABATIC DIAGRAM.

different points of the stroke. This is shown in the horizontal lines. But in compressing air we produce heat, and it is important to know the temperature at any given pressure, also the relative volume. All of these are shown in the diagram. The initial volume of air equal to one is taken and divided into ten equal parts, each division between two vertical lines, shown by the figures at the top, representing one-tenth of the original volume.

The vertical and horizontal lines are the measures of volumes, pressures, and temperatures. The figures at the left indicate pressure in atmospheres above a vacuum; the corresponding figures at the right denote pressures by the gauge. At the top are volumes from one-tenth to one; at the bottom degrees of temperature from zero to $1,000^{\circ}$ F. The two curves which begin at the lower left-hand corner and extend to the upper right are the lines of compression.

These curves start from atmospheric pressure, and in all computations for pressure the zero of atmospheric pressures is the starting-point, which would be represented by an additional line at equal distance of the other lines, below the bottom line.

The upper curve is the "adiabatic" curve, or that which represents the pressure at any point on the stroke, with the heat developed by compression remaining in the air; the lower is the "isothermal," or the pressure curve uninfluenced by heat. The three curves which begin at the lower right-hand corner and rise to the left are heat curves, and represent the increase of temperature corresponding with different pressures and volumes, assuming in one case that the temperature of the air before admission to the compressor is zero, in another 60° , and in another 100° .

Beginning with the adiabatic curve, we find that for one volume of air, when compressed without cooling, the curve intersects the first horizontal line at a point between 0.6 and 0.7 volume, the gauge pressure being 14.7 pounds. If we assume that this air was admitted to the compressor at a temperature of zero, it will reach about 100° when the gauge pressure is 14.7 pounds. If the air had been admitted to the compressor at 60° , it would register about 176° at 14.7 pounds gauge pressure. If the air were 100° before compression, it would go up to about 230° at this pressure. Following this adiabatic curve until it intersects line No. 5, representing a pressure of five atmospheres above a vacuum (58.8 pounds gauge pressure), we see that the total increase of temperature on the zero heat curve is about

270° ; for the 60° curve it is about 370° ; and for the 100° curve it is about 435° . The diagram shows that when a volume of air is compressed adiabatically to 21 atmospheres (294 pounds gauge pressure), it will occupy a volume a little more than one-tenth; the total increase of temperature with an initial temperature of zero, is about 650° ; with 60° initial temperature it is 800° , and with 100° initial it is 900° . It will be observed that the zero heat curve is flatter than the others, indicating that when free air is admitted to a compressor cold, the relative increase of temperature is less than when the air is hot. This points to the importance of low initial temperature. It is plain that a high initial temperature means a higher temperature throughout the stroke of a compressor. The diagram gives the loss of temperature during compression from initial temperatures of 0° , 60° , 100° . If we compare the compression line from zero with the compression line from 100° , we observe that in compressing the air from, say, 1 atmosphere to 10 atmospheres, the original difference, which at the start was only 100° , has now been about doubled, that is, it has reached 200° ; and in carrying the compression to 20 atmospheres, the difference now becomes about 250° . Each horizontal division represented by the figures at the bottom is equal to 100° , and the space between any two adjacent horizontal lines may be subdivided into 100 equal parts representing 1° each.

Where there is a system of cooling the air during compression, the lines on the indicator cards can be traced between the adiabatic and isothermal curves on the diagram. In practice, the best compressors show a line about midway between these two curves.

For all practical purposes in using this diagram, it is best to follow the adiabatic curve in all determinations, except where the exact pressure line is known. This diagram will be found convenient to those who are called upon to figure the pressure at different points in the stroke of an air compressor, and it points out the common error of neglecting to take into consid-

eration in one's figures the fact that, at the beginning of the stroke, one atmosphere in volume already exists. Beginning at the lower left-hand corner, the adiabatic pressure curve intersects the first horizontal line at that point in the stroke where the pressure on the gauge will register 14.7 pounds.

The next horizontal line shows where the gauge reaches 29.4 pounds, and it is evident here that the piston of an air compressor travels much farther in reaching 14.7 pounds than in doubling that pressure or in reaching 29.4 pounds; thus an air compressor is an engine of unevenly distributed resistance. During the early stages of the stroke it has a slowly accumulating load to carry, while later on this load is multiplied very rapidly.

For computing the pressure at the intersection of the adiabatic curve with the horizontal lines in the diagram, the lines representing the volumes of compression are the starting-points in the formula, and the compression $= \frac{1}{10}, \frac{2}{10}$, etc., of which the complements $\frac{9}{10}, \frac{8}{10}$, etc., are the terms of the volume used in the equation. Then by inversion, $\frac{V^{1.406}}{V_1} = \frac{P}{P}$ and $\frac{10}{9} = 1.111$ $\log. 0.045714 \times 1.406 = \log. 0.064273$, of which the index is 1.159 in absolute atmospheres, and $1.159 - 1 = .159$ in hundredths of the space above one atmosphere at the intersection of the first vertical line representing a compression of $\frac{1}{10}$ and marked .9 at the top of the diagram. For the position of the curve at the second vertical line and following the same notation is to be used, viz., $\frac{10}{8} = 1.25$ $\log. 0.0961 \times 1.406 = \log. 0.136255$, of which the index is 1.368 in absolute atmospheres and $1.368 - 1 = .368$ in hundredths of the space at the intersection of the second vertical line representing a compression of $\frac{2}{10}$ and marked .8 at the top of the diagram. At the compression of $\frac{9}{10}$ and marked .1 in the extension of the diagram the

point of intersection with the adiabatic curve will be carried up to 25.47 atmospheres.

For locating the isothermic curve the first index of the compressions is to be used, and the intersections of the curve with the verticals will be $\frac{10}{9} = 1.111$ absolute atmospheres and $1.111 - 1 = .111$ on the scale of the diagram, $\frac{10}{8} = 1.25 - 1 = .25$, and so on for each intersection on the isothermic curve with the compression verticals of the diagram.

For the temperature curves from three different initial temperatures of 0° , 60° , and 100° , the temperature of compression for each increment or atmosphere as represented in the diagram is found by the common logarithm of the quotient of the absolute pressures multiplied by the exponent of the ratio of expansion by heat, .2906. Then $\frac{P}{P_1}^{0.29} = \frac{T}{T_1} \times 100$ to correspond with the 100° divisions at the bottom of the diagram; and for the gauge pressure of 14.7 pounds, which is 2 absolute atmospheres as marked on the left-hand margin, $\frac{29.4}{14.7}$ is 2, $\log. 0.30103 \times .29 = \log. 0.0033298$, the index of which is $1.08 \times 100 = 108$, the point of meeting of the expansion curve with the horizontal line representing 2 atmospheres absolute.

Then for the curve starting at 60° , or 520° absolute, we have the same index $\frac{1.08 \times 520}{460} = 1.22 \times 100^\circ = 122^\circ + 60^\circ$, the starting-point in the scale, $= 182^\circ$ the point of intersection of the 60° heat curve with the horizontal line of 2 atmospheres absolute. Again for the curve starting at an initial temperature of 100° F. we have the same index $\frac{1.08 \times 560}{460} = 1.315 \times 100^\circ = 131.5 + 100$ as the starting-point $= 231.5$, the point of meeting of the curve from 100° initial temperature with the horizontal line of 2 atmospheres absolute. And so on throughout the diagram.

There is a slight difference in the results from the equations of various authors for the mean pressure from air compression. The following formula is different from the one used in Mr. Shone's tables—Tables XVI., XVII.: $\frac{n}{n-1} P \left[\left(\frac{P_2}{P} \right)^{\frac{n-1}{n}} - 1 \right]$ = mean pressure. $\frac{n}{n-1} = \frac{1.406}{.406} = 3.463$ and $\frac{n-1}{n} = .29$. Then for compressing air from atmospheric pressure to 60 pounds gauge pressure $P = 14.7$ and $P_2 = 74.7$. Then $3.463 \times 14.7 \times \left[\left(\frac{74.7}{14.7} \right)^{.29} - 1 \right]$ = mean pressure, which must be worked out as follows: The ratio of the pressures $\frac{74.7}{14.7} = 5.08$ log. $0.705864 \times .29 = 0.2047005$ index 1.602 — 1 = .602 $\times 14.7 \times 3.463 = 30.63$, the mean pressure of adiabatic compression from atmospheric pressure to 60 pounds gauge pressure.

COMPRESSED AIR TABLES.

In Table XVI. is given the absolute pressure in pounds per square inch from the zero of pressure to 3,014.7 pounds absolute in column 1 on the left, and the gauge pressure inversely from a vacuum to 0 or atmospheric pressure, and up to 3,000 pounds in column 8 at the right side of the table.

Column 2 is the absolute temperature, Fahrenheit, of compression from the absolute zero of temperature up to normal temperature at atmospheric pressure, and so on to 3,014.7, and is by the formula $\left(\frac{P}{P} \right)^{0.29} \times (461.2 + T)$ in Fahrenheit degrees.

Column 3 = (column 2 — 461.2) = $t - 461.2^\circ$ Fahrenheit t = column 2.

Column 4 is the absolute temperature in Centigrade degrees = $t = \left(\frac{P}{P} \right)^{0.29} \times (274 + T)$ in Centigrade degrees.

Column 5 = $t - 274$ or column 4 — 274° C. Centigrade t = column 5.

Column 6 is the adiabatic compression of 100 volumes =
 $\text{column } 7 \times \frac{t}{.461.2 + T} \text{ or column } 7 \times \frac{\text{col. } 2}{521.2}.$

Column 7 is the isothermal compression of 100 volumes =
 $\frac{P \times 100}{p} = \frac{14.7 \times 100}{\text{column } 1}.$

The tables were originally computed by Mr. Shone in England up to 100 pounds gauge pressure, using the absolute temperatures of 461.2 and 274° C. The error is too small to warrant a recomputation, and for symmetry the author has used the same formula for the extension to 3,000 pounds.

TABLE XVI.—PRESSURES, TEMPERATURES, AND VOLUMES BY ADIABATIC AND ISOTHERMAL AIR COMPRESSION. (Shone.)

Absolute pressure.	Absolute temperature, Fahrenheit.	Temperature from 60° F. at atmospheric pressure.	Absolute temperature, Centigrade.	Temperature from 15.56° Centigrade.	Volumes from 100 at atmospheric pressure, adiabatic.	Volumes from 100 at atmospheric pressure, isothermal.	Gauge pressure.
1	2	3	4	5	6	7	8
0.0	0.0	— 461.20	0.00	— 274.00	Infinite.	Infinite.	— 14.7
1.	+ 239.05	— 222.15	+ 132.81	— 141.19	674.21	1,470.00	— 13.7
2.	202.27	— 168.93	162.36	— 111.64	412.16	735.	— 12.7
3.	328.74	— 132.47	182.63	— 91.37	309.06	490.	— 11.7
4.	357.34	— 103.86	198.52	— 75.48	251.96	367.50	— 10.7
5.	381.23	— 79.98	211.79	— 62.21	215.04	294.	— 9.7
6.	401.93	— 59.27	223.29	— 50.71	188.93	245.	— 8.7
7.	420.30	— 40.90	233.50	— 40.50	169.35	210.	— 7.7
8.	436.60	— 24.65	242.72	— 31.28	154.03	183.75	— 6.7
9.	452.08	— 9.12	251.16	— 22.84	141.67	163.333	— 5.7
10.	466.10	+ 4.90	258.94	— 15.06	131.46	147.	— 4.7
11.	479.17	18.06	266.21	— 7.79	122.86	133.636	— 3.7
12.	491.41	30.21	273.02	— 0.98	115.50	122.50	— 2.7
13.	502.95	41.75	279.41	+ 5.41	109.12	113.077	— 1.7
14.	513.88	52.69	285.49	11.49	103.53	105.	— 0.7
14.7	521.20	60.00	289.56	15.56	100.00	100.	0.
15.7	531.24	70.04	295.13	21.13	95.435	93.631	1.
16.7	540.84	79.64	300.47	26.47	91.341	88.024	2.
17.7	550.04	88.84	305.58	31.58	87.646	83.051	3.
18.7	558.88	97.68	310.49	36.49	84.292	78.610	4.
19.7	567.38	106.18	315.21	41.21	81.231	74.619	5.
20.7	575.59	114.39	319.77	45.77	78.443	71.031	6.
21.7	583.52	122.32	324.18	50.18	75.842	67.742	7.
22.7	591.19	129.99	328.44	54.44	73.454	64.758	8.
23.7	598.63	137.43	332.57	58.57	71.240	62.025	9.
24.7	605.85	144.65	336.58	62.58	69.180	59.574	10.
25.7	612.86	151.66	340.48	66.48	67.258	57.198	11.
26.7	619.68	158.48	344.27	70.27	65.459	55.056	12.
27.7	626.33	165.13	347.96	73.96	63.773	53.069	13.
28.7	632.80	171.60	351.56	77.56	62.187	51.220	14.

TABLE XVI. (Continued).

Absolute pressure.	Absolute temperature, Fahrenheit.	Temperature from 60° F. at atmospheric pressure.	Absolute temperature, Centigrade.	Temperature from 15.56° Centigrade	Volumes from 100 at atmospheric pressure, adiabatic.	Volume from 100 at atmospheric pressure, isothermal.	Gauge pressure.
1	2	3	4	5	6	7	8
29.7	639.12	177.92	355.07	81.07	60.693	49.495	15.
30.7	645.29	184.09	358.49	84.49	59.283	47.883	16.
31.7	651.31	190.11	361.84	87.84	57.949	46.372	17.
32.7	657.21	196.01	365.12	91.12	56.685	44.954	18.
33.7	662.97	201.77	368.32	94.32	55.485	43.620	19.
34.7	668.62	207.42	371.46	97.46	54.345	42.363	20.
35.7	674.15	212.95	374.53	100.53	53.260	41.176	21.
36.7	679.57	218.37	377.54	103.54	52.225	40.054	22.
37.7	684.89	223.69	380.49	106.49	51.238	38.992	23.
38.7	690.11	228.91	383.39	109.39	50.295	37.984	24.
39.7	695.23	234.03	386.24	112.24	49.392	37.028	25.
40.7	700.27	239.07	389.04	115.04	48.527	36.118	26.
41.7	705.22	244.02	391.79	117.79	47.698	35.252	27.
42.7	710.08	248.88	394.49	120.49	46.902	34.426	28.
43.7	714.86	253.66	397.15	123.15	46.136	33.638	29.
44.7	719.57	258.37	399.76	125.76	45.402	32.886	30.
45.7	724.20	263.00	402.33	128.33	44.695	32.166	31.
46.7	728.76	267.56	404.87	130.87	44.013	31.478	32.
47.7	733.25	272.05	407.36	133.36	43.356	30.818	33.
48.7	737.68	276.48	409.82	135.82	42.722	30.185	34.
49.7	742.04	280.84	412.24	138.24	42.110	29.577	35.
50.7	746.34	285.14	414.63	140.63	41.518	28.994	36.
51.7	750.58	289.38	416.99	142.99	40.947	28.433	37.
52.7	754.76	293.56	419.32	145.32	40.393	27.894	38.
53.7	758.88	297.68	421.60	147.60	39.858	27.374	39.
54.7	762.95	301.75	423.86	149.86	39.339	26.874	40.
55.7	766.97	305.77	426.09	152.09	38.836	26.391	41.
56.7	770.94	309.74	428.30	154.30	38.349	25.926	42.
57.7	774.86	313.66	430.48	156.48	37.876	25.477	43.
58.7	778.73	317.53	432.63	158.63	37.416	25.043	44.
59.7	782.56	321.36	434.76	160.76	36.970	24.623	45.
60.7	786.33	325.13	436.85	162.85	36.537	24.217	46.
61.7	790.07	328.87	438.93	164.93	36.115	23.825	47.
62.7	793.76	332.56	440.98	166.98	35.706	23.445	48.
63.7	797.41	336.21	443.01	169.01	35.307	23.077	49.
64.7	801.02	339.82	445.01	171.01	34.918	22.720	50.
65.7	804.59	343.39	446.99	172.99	34.540	22.374	51.
66.7	808.13	346.93	448.96	174.96	34.172	22.039	52.
67.7	811.62	350.42	450.90	176.90	33.813	21.713	53.
68.7	815.08	353.88	452.82	178.82	33.462	21.397	54.
69.7	818.50	357.30	454.72	180.72	33.121	21.090	55.
70.7	821.89	360.69	456.61	182.61	32.787	20.792	56.
71.7	825.25	364.05	458.47	184.47	32.462	20.502	57.
72.7	828.57	367.37	460.32	186.32	32.144	20.220	58.
73.7	831.86	370.66	462.14	188.14	31.834	19.946	59.
74.7	835.11	373.91	463.95	189.95	31.531	19.679	60.
75.7	838.34	377.14	465.74	191.74	31.235	19.419	61.
76.7	841.54	380.34	467.52	193.52	30.945	19.166	62.
77.7	844.70	383.50	469.28	195.28	30.662	18.919	63.
78.7	847.84	386.64	471.02	197.02	30.385	18.679	64.
79.7	850.95	389.75	472.75	198.75	30.113	18.444	65.
80.7	854.04	392.84	474.47	200.47	29.848	18.216	66.
81.7	857.09	395.89	476.16	202.16	29.588	17.993	67.

TABLE XVI. (Continued).

Absolute pressure.	Absolute temperature, Fahrenheit.	Temperature from 60° F. at atmospheric pressure.	Absolute temperature, Centigrade.	Temperature from 15.56° Centigrade.	Volumes from 100 at atmospheric pressure, adiabatic.	Volume, from 100 at atmospheric pressure, isothermal.	Gauge pressure.
1	2	3	4	5	6	7	8
82.7	860.12	398.92	477.84	203.84	29.334	17.775	68.
83.7	863.12	401.92	479.51	205.51	29.084	17.563	69.
84.7	866.10	404.90	481.17	207.17	28.840	17.355	70.
85.7	869.05	407.85	482.81	208.81	28.601	17.153	71.
86.7	871.98	410.78	484.43	210.43	28.366	16.955	72.
87.7	874.89	413.69	486.05	212.05	28.136	16.762	73.
88.7	877.77	416.57	487.65	213.65	27.911	16.573	74.
89.7	880.63	419.43	489.24	215.24	27.689	16.388	75.
90.7	883.46	422.26	490.81	216.81	27.472	16.207	76.
91.7	886.28	425.08	492.38	218.38	27.259	16.031	77.
92.7	889.07	427.87	493.93	219.93	27.050	15.858	78.
93.7	891.84	430.64	495.47	221.47	26.845	15.688	79.
94.7	894.59	433.39	496.99	222.99	26.643	15.523	80.
95.7	897.32	436.12	498.51	224.51	26.445	15.361	81.
96.7	900.03	438.83	500.02	226.02	26.251	15.202	82.
97.7	902.72	441.52	501.51	227.51	26.060	15.046	83.
98.7	905.39	444.19	502.99	228.99	25.872	14.894	84.
99.7	908.04	446.84	504.47	230.47	25.687	14.744	85.
100.7	910.67	449.47	505.93	231.93	25.506	14.598	86.
101.7	913.28	452.08	507.38	233.38	25.328	14.454	87.
102.7	915.88	454.68	508.82	234.82	25.152	14.314	88.
103.7	918.46	457.26	510.26	236.26	24.980	14.176	89.
104.7	921.02	459.82	511.68	237.68	24.753	14.040	90.
105.7	923.56	462.36	513.09	239.09	24.643	13.907	91.
106.7	926.08	464.88	514.49	240.49	24.479	13.777	92.
107.7	928.59	467.39	515.88	241.88	24.318	13.649	93.
108.7	931.08	469.88	517.27	243.27	24.159	13.523	94.
109.7	933.56	472.36	518.64	244.64	24.002	13.400	95.
110.7	936.02	474.82	520.01	246.01	23.848	13.279	96.
111.7	938.46	477.26	521.37	247.37	23.696	13.160	97.
112.7	940.89	479.69	522.72	248.72	23.547	13.044	98.
113.7	943.31	482.11	524.06	250.06	23.399	12.929	99.
114.7	945.71	484.51	525.39	251.39	23.254	12.816	100.
119.7	957.44	496.24	531.91	257.91	22.558	12.280	105.
124.7	968.91	507.71	538.27	264.27	21.893	11.788	110.
129.7	980.11	518.91	544.50	270.50	21.304	11.333	115.
134.7	990.80	529.60	550.80	276.80	20.822	10.913	120.
139.7	1,001.22	540.02	556.23	282.23	20.202	10.522	125.
144.7	1,011.64	550.44	562.02	288.02	19.718	10.159	130.
149.7	1,021.55	560.35	567.53	293.53	19.245	9.819	135.
154.7	1,031.19	569.99	572.88	298.88	18.794	9.502	140.
159.7	1,041.86	580.66	578.81	304.81	18.391	9.205	145.
164.7	1,049.95	588.75	583.30	309.30	17.974	8.925	150.
174.7	1,068.35	607.15	593.53	319.53	17.240	8.414	160.
184.7	1,085.66	624.46	603.14	329.14	16.576	7.958	170.
194.7	1,102.59	641.39	612.55	338.55	15.968	7.550	180.
204.7	1,118.49	657.29	621.38	347.38	15.403	7.181	190.
214.7	1,134.23	673.03	630.12	356.12	14.896	6.846	200.
264.7	1,205.48	744.28	669.71	395.71	12.838	5.553	250.
314.7	1,267.08	805.88	703.93	429.93	11.355	4.671	300.
364.7	1,332.96	871.76	740.53	466.53	10.394	4.030	350.
414.7	1,372.89	911.69	762.71	488.71	9.334	3.544	400.
464.7	1,417.70	956.50	787.61	513.61	8.603	3.163	450.

TABLE XVI. (*Continued*).

Absolute pressure.	Absolute temperature, Fahrenheit.	Temperature from 60° F. at atmospheric pressure.	Absolute temperature, Centigrade.	Temperature from 15.50° Centigrade.	Volumes, from 100 at atmospheric pressure, adiabatic.	Volume from 100 at atmospheric pressure, isothermal.	Gauge pressure.
1	2	3	4	5	6	7	8
514.7	1,461.49	1,000.29	811.94	537.94	8.003	2.556	500.
614.7	1,538.84	1,077.64	854.91	580.91	7.058	2.391	600.
714.7	1,607.64	1,146.44	893.13	619.13	6.340	2.056	700.
814.7	1,669.92	1,208.72	927.73	653.73	5.780	1.804	800.
914.7	1,726.78	1,265.58	959.32	685.32	5.324	1.607	900.
1,014.7	1,774.42	1,313.22	985.79	711.79	4.928	1.448	1,000.
1,214.7	1,875.32	1,414.12	1,041.84	767.84	4.353	1.210	1,200.
1,414.7	1,959.71	1,498.51	1,088.73	814.73	3.880	1.032	1,400.
1,614.7	2,024.71	1,563.51	1,124.84	850.84	3.534	0.910	1,600.
1,814.7	2,106.63	1,645.43	1,170.35	896.35	3.274	0.810	1,800.
2,014.7	2,171.05	1,709.85	1,206.14	932.14	3.036	0.729	2,000.
2,514.7	2,315.17	1,853.97	1,286.20	1,012.20	2.594	0.584	2,500.
3,014.7	2,440.41	1,979.21	1,355.78	1,081.78	2.280	0.457	3,000.

In Table XVII. are given the gauge pressure; ratios of compression in volumes adiabatic and isothermal; points of stroke at gauge pressure, adiabatic; points of stroke at gauge pressure, isothermal; the mean pressure at full stroke adiabatic and isothermal, for compression from 1 pound to 3,000 pounds.

Column 1 = gauge pressure, $p - P$.

Column 2 = $100 \div$ by the mean pressure at full stroke, adiabatic, as found in column 6, Table XVI., and represents the ratio of volumes at atmospheric pressure from gauge pressure, adiabatic.

Column 3 = $100 \div$ by column 7 in Table XVI., and represents the ratio of volumes at atmospheric pressure from gauge pressure, isothermal.

Column 4 = $1 \div$ by column 2 in this table, and represents the point of stroke of a piston at the moment the gauge pressure is reached, adiabatic.

Column 5 = $1 \div$ by column 3 in this table, and represents the point of stroke of a piston at the moment the gauge pressure is reached, isothermal.

Column 6 = $p \times \frac{1 + H}{R} - P$, in which R is the ratio of the

adiabatic compression in column 2 of this table and H = the hyperbolic logarithm of the ratio R in column 2 of this table.

Column 7 = $p \times \frac{1 + H}{R} - P$; in which R is the ratio of isothermal compression found in column 3, and equals $\frac{P}{p}$ or absolute pressure divided by the normal pressure. H = the hyperbolic logarithm of the ratio of isothermal compression $\frac{P}{p}$ in column 3 of this table.

In the absence of tables of hyperbolic logarithms, the common logarithm of a number $\times 2.302585$ = hyperbolic logarithm.

TABLE XVII.—GAUGE PRESSURES, RATIOS OF COMPRESSION, POINTS OF STROKE, AND MEAN PRESSURE FOR FULL STROKE IN AIR COMPRESSION. (Shone.)

Gauge pressure.	Ratio of volume at atmospheric pressure, adiabatic.	Ratio of volume at atmospheric pressure, isothermal.	Point of stroke at gauge pressure, adiabatic.	Point of stroke at gauge pressure, isothermal.	Mean pressure at full stroke, adiabatic.	Mean pressure at full stroke, isothermal.
1	2	3	4	5	6	7
1	1.0478	1.0680	0.954	0.936	0.978	0.967
2	1.0948	1.1361	.913	.880	1.937	1.874
3	1.1409	1.2041	.876	.831	2.846	2.680
4	1.1864	1.2721	.843	.786	3.805	3.513
5	1.2310	1.3401	.812	.746	4.615	4.303
6	1.2748	1.4078	.784	.710	5.419	5.055
7	1.3185	1.4762	.758	.677	6.326	5.762
8	1.3614	1.5442	.735	.648	7.101	6.347
9	1.4037	1.6122	.712	.620	7.865	7.000
10	1.4455	1.6803	.692	.595	8.737	7.626
11	1.4868	1.7483	.673	.572	9.479	8.226
12	1.5277	1.8164	.655	.551	10.211	8.802
13	1.5681	1.8844	.638	.531	10.934	9.280
14	1.6081	1.9524	.622	.512	11.647	9.817
15	1.6476	2.0204	.607	.495	12.353	10.336
16	1.6868	2.0884	.593	.479	13.049	10.837
17	1.7257	2.1565	.579	.464	13.738	11.320
18	1.7641	2.2245	.567	.450	14.314	11.723
19	1.8023	2.2925	.555	.436	14.990	12.180
20	1.8401	2.3605	.543	.424	15.657	12.623
21	1.8776	2.4286	.533	.412	16.317	13.052
22	1.9148	2.4966	.522	.401	16.870	13.470
23	1.9517	2.5646	.512	.390	17.516	13.818
24	1.9883	2.6327	.503	.380	18.157	14.215
25	2.0246	2.7007	.494	.370	18.695	14.602
26	2.0607	2.7687	.485	.361	19.324	14.976
27	2.0965	2.8367	.477	.353	19.946	15.344
28	2.1321	2.9048	.469	.344	20.470	15.651
29	2.1675	2.9728	.461	.336	21.081	16.002
30	2.2025	3.0408	.454	.329	21.597	16.345

TABLE XVII. (*Continued*).

Gauge pressure.	Ratio of volume at atmospheric pressure, adiabatic.	Ratio of volume at atmospheric pressure, isothermal.	Point of stroke at gauge pressure, adiabatic.	Point of stroke at gauge pressure, isothermal.	Mean pressure at full stroke, adiabatic.	Mean pressure at full stroke, isothermal.
1	2	3	4	5	6	7
31	2.2374	3.1088	.447	.322	22.199	16.679
32	2.2721	3.1769	.440	.315	22.704	17.006
33	2.3065	3.2449	.434	.308	23.295	17.281
34	2.3407	3.3129	.427	.302	23.794	17.594
35	2.3747	3.3810	.421	.296	24.288	17.903
36	2.4086	3.4490	.415	.290	24.865	18.204
37	2.4422	3.5170	.409	.284	25.352	18.500
38	2.4757	3.5850	.404	.279	25.923	18.790
39	2.5089	3.6531	.399	.274	26.402	19.032
40	2.5420	3.7211	.393	.269	26.878	19.311
41	2.5749	3.7891	.388	.264	27.350	19.586
42	2.6076	3.8571	.383	.259	27.905	19.855
43	2.6402	3.9252	.379	.255	28.370	20.118
44	2.6726	3.9932	.374	.250	28.834	20.342
45	2.7049	4.0612	.370	.246	29.295	20.598
46	2.7370	4.1293	.365	.242	29.833	20.849
47	2.7689	4.1973	.361	.238	30.285	21.096
48	2.8007	4.2653	.357	.234	30.737	21.339
49	2.8323	4.3333	.353	.231	31.187	21.544
50	2.8638	4.4014	.349	.227	31.632	21.780
51	2.8952	4.4694	.345	.224	32.154	22.012
52	2.9264	4.5374	.342	.220	32.594	22.040
53	2.9575	4.6054	.338	.217	33.033	22.465
54	2.9884	4.6735	.335	.214	33.468	22.656
55	3.0193	4.7415	.331	.211	33.901	22.873
56	3.0499	4.8095	.328	.208	34.330	23.089
57	3.0805	4.8776	.325	.205	34.758	23.301
58	3.1110	4.9456	.321	.202	35.183	23.511
59	3.1413	5.0136	.318	.199	35.607	23.688
60	3.1715	5.0816	.315	.197	36.027	23.892
61	3.2016	5.1497	.312	.194	36.448	24.092
62	3.2315	5.2177	.309	.192	36.864	24.292
63	3.2614	5.2857	.307	.189	37.277	24.487
64	3.2911	5.3537	.304	.187	37.690	24.653
65	3.3208	5.4218	.301	.184	38.095	24.844
66	3.3503	5.4898	.298	.182	38.509	25.033
67	3.3797	5.5578	.296	.180	38.914	25.219
68	3.4091	5.6259	.293	.178	39.317	25.403
69	3.4383	5.6939	.291	.176	39.720	25.559
70	3.4674	5.7619	.288	.174	40.121	25.738
71	3.4964	5.8299	.286	.172	40.518	25.916
72	3.5253	5.8980	.284	.170	40.913	26.093
73	3.5541	5.9660	.281	.168	41.237	26.264
74	3.5829	6.0340	.279	.166	41.631	26.411
75	3.6115	6.1020	.277	.164	42.021	26.582
76	3.6400	6.1701	.275	.162	42.411	26.750
77	3.6685	6.2381	.273	.160	42.797	26.916
78	3.6969	6.3061	.271	.159	43.182	27.079
79	3.7251	6.3742	.268	.157	43.566	27.218
80	3.7533	6.4422	.266	.155	43.882	27.379
81	3.7814	6.5102	.264	.154	44.260	27.538
82	3.8094	6.5782	.263	.152	44.639	27.695
83	3.8373	6.6463	.261	.150	45.017	27.851
84	3.8652	6.7143	.259	.149	45.393	27.983

TABLE XVII. (Continued).

Gauge pressure.	Ratio of volume at atmospheric pressure, adiabatic.	Ratio of volume at atmospheric pressure, isothermal.	Point of stroke at gauge pressure, adiabatic.	Point of stroke at gauge pressure, isothermal.	Mean pressure at full stroke, adiabatic.	Mean pressure at full stroke, isothermal.
1	2	3	4	5	6	7
85	3.8929	6.7823	.257	.147	45.700	28.136
86	3.9260	6.8503	.255	.146	46.137	28.286
87	3.9482	6.9184	.253	.145	46.443	28.436
88	3.9757	6.9864	.252	.143	46.813	28.584
89	4.0032	7.0544	.250	.142	47.115	28.709
90	4.0306	7.1224	.248	.140	47.482	28.855
91	4.0579	7.1905	.246	.139	47.487	28.999
92	4.0851	7.2585	.245	.138	48.209	29.141
93	4.1122	7.3265	.243	.136	48.507	29.282
94	4.1393	7.3946	.242	.135	48.869	29.401
95	4.1663	7.4626	.240	.134	49.227	29.541
96	4.1932	7.5306	.238	.133	49.522	29.678
97	4.2201	7.5986	.237	.132	49.878	29.813
98	4.2469	7.6667	.235	.130	50.234	29.948
99	4.2736	7.7347	.234	.129	50.525	30.063
100	4.3003	7.8027	.233	.128	50.878	30.195
105	4.433	8.143	.225	.123	52.451	30.824
110	4.567	8.483	.219	.118	54.034	31.427
115	4.693	8.823	.213	.113	55.662	32.004
120	4.802	9.163	.208	.109	57.351	32.552
125	4.950	9.503	.202	.105	58.656	33.091
130	5.071	9.843	.197	.102	60.153	33.615
135	5.195	10.184	.192	.098	61.587	34.102
140	5.328	10.524	.188	.095	62.650	34.649
145	5.437	10.864	.184	.092	64.199	35.062
150	5.563	11.204	.179	.089	65.706	35.368
160	5.800	11.884	.172	.084	68.369	36.312
170	6.033	12.565	.166	.080	70.926	37.293
180	6.263	13.245	.159	.076	73.491	37.966
190	6.492	13.925	.154	.072	76.797	38.706
200	6.713	14.605	.149	.068	78.189	39.463
250	7.789	18.007	.128	.055	89.035	42.475
300	8.806	21.408	.113	.047	98.780	44.998
350	9.705	24.808	.103	.040	108.276	47.189
400	10.713	28.210	.093	.035	115.889	49.039
450	11.623	31.612	.086	.032	123.594	50.776
500	12.487	35.014	.080	.029	131.423	52.262
600	14.168	41.816	.070	.024	143.646	54.822
700	15.773	48.618	.063	.021	155.541	57.055
800	17.301	55.422	.058	.018	166.163	58.948
900	18.783	62.224	.053	.016	176.929	60.671
1,000	20.292	69.027	.049	.014	185.703	62.214
1,200	22.972	82.632	.043	.012	203.824	64.862
1,400	25.773	96.238	.039	.010	219.442	67.069
1,600	28.296	109.843	.035	.009	232.994	68.941
1,800	30.543	123.449	.033	.008	247.705	70.772
2,000	32.938	137.054	.030	.007	260.105	72.133
2,500	38.550	171.068	.026	.006	289.327	75.326
3,000	43.859	205.081	.023	.005	313.902	78.152

Chapter X.

THE COMPRESSED AIR INDICATOR CARD

THE COMPRESSED AIR INDICATOR CARD.

THE theoretical conditions of air compression and expansion may be diagrammatically expressed to represent both the theoretical and the practical lines of compression and expansion, with the difference that the theoretical lines or curves may be computed from the known law of thermodynamics, but the practical lines or curves must be found and based on the heat-absorbing element of the compressor, which is an uncertain

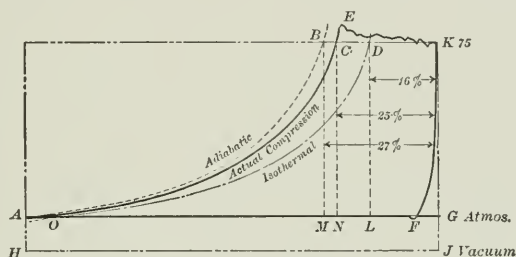


FIG. 46.—COMPRESSED AIR INDICATOR CARD.

amount depending much on the velocity of the pistons, or rather the velocity of transmission through the compressor and the degree of absorption of heat by the walls of the cylinder.

Referring to Fig. 46 we have the adiabatic or heat line $A-B$, which represents the work done if there were no cooling effect in the cylinder, the line $A-C$ representing the actual work done in the cylinder, and the isothermal or constant temperature line $A-D$, which is the line the indicator would make if all the heat generated could be carried off during the work of compression.

This latter condition does not exist in our high-speed machines of to-day, but one can imagine it to exist in a machine where the piston travels slow enough to allow all the heat to be carried off by the water jacket or by radiation. In following the movement of the piston in the cylinder, suppose it starts at A ,

the cylinder then being full of free air, and moves to the right; the pressure in the cylinder at any point is represented on line *A-C*. When the piston reaches *C*, it has compressed the air to the receiver pressure, and it must then push the compressed air out through the discharge valves into the receiver. Owing to the weight of the discharge valves and the tension of the springs holding them to their seats, the pressure in the cylinder reaches a few pounds above the receiver pressure before the valves open, as shown at *E*, and there gradually drops to the receiver pressure at the end of stroke, the irregularities in the line being due to the fluttering of the discharge valves and the vibration of the indicator arm.

The piston, having reached the end of stroke, comes to a standstill while the crank is passing the dead centre; and as the current of air that held the discharge valves open in passing out of the cylinder has ceased, the discharge valves close by the tension of the springs back of them. The piston now starts to recede—the air under pressure that was left in the cylinder due to the clearance space expanding until it becomes atmospheric pressure at *F*, when the inlet valves open and the cylinder is filled with free air. If the indicator line follows along the atmospheric line, we know that the inlet area is not restricted and we are getting a volume of free air at atmospheric pressure represented by the travel of piston from *F* to *A*, this representing the actual free air capacity of the compressor. The volume between *G* and *F* representing the air contained in the clearance space, expanded, is lost as far as the capacity of the compressor is considered; and although this air required work in compressing it to 75 pounds pressure, it has given out its work in expanding, helping to compress the air on the other side of the piston.

The only loss in work due to the clearance space is that resulting from the small amount of cooling that the confined air has been subjected to, its volume, when hot, having been a trifle more and having required more work to compress it; but this is

rarely taken into account. We thus see that the clearance space in the cylinder is not a loss of power, but a loss of capacity, which is allowed for by deducting anywhere from 3 to 6 per cent of the cylinder volume, according to the design of the air cylinder and the length of stroke of same—it being evident that the longer the stroke for the same size cylinder the less will be the percentage of clearance. On some indicator cards it is noticed that the intake air pressure falls below the atmospheric line, showing that the air inlet is restricted, or, as is common on air cylinders having poppet inlet valves closed by a spring, the tension of the spring when the piston is moving slow at the end of the stroke will close the valves before the piston has completed its stroke, so that when the end of stroke is reached a partial vacuum is formed in the cylinder. Where these defects exist, the piston must travel a distance of $A-O$ before the atmospheric line is reached, and the volume of the cylinder would be $O-F$, instead of $A-F$, making the 6-per-cent allowance for clearance necessary, while 2 to 3 per cent should be sufficient on a well-designed compressor.

The temperature of the air at 75 pounds gauge pressure without any cooling is 419° , although this is somewhat lower in the cylinder, due to the jacket cooling; and from actual readings on thermometers placed in the discharge pipe close to the cylinder, the temperature is from 300° to 360° , according to the size and speed of the compressor.

Referring again to Fig. 46 we have the volume $C-K-N-G$, representing about 25 per cent of the free air volume at, say, 320° temperature, to put into the receiver at each stroke of the compressor piston. As the receiver is anywhere from 10 to 20 feet from the compressor, and as it has a large surface exposed for radiation, its temperature will be considerably less than that of the air leaving the cylinder, which will consequently be cooled and reduced in volume; and as the air is generally used a considerable distance from the compressor, it will have reached atmospheric temperature by the time it is used, and the

original volume $C-K-N-G$, when leaving the cylinder, will have shrunk to $D-K-L-G$ by the time it is used, being then only $\frac{16}{25}$ of what it would have been, had the air been used hot directly as it left the compressor. So that the actual loss by shrinkage within the cylinder of a compressor of the best construction may be no more than from 2 to 3 per cent of the volume together with the clearance of an average from all causes, say of 3 per cent, which with the cooling by transmission brings the volume of free air entering the compressor to about 16 per cent at 75 pounds gauge pressure.

THE MEAN PRESSURE OF AN INDICATOR CARD.

The indicator is the proper instrument for investigating the internal work of compressing air, and the indicator card is the best representation of the work of the compressor.

In Fig. 47 is shown a facsimile of an indicator card from a 22 by 30 inch air cylinder running at 50 revolutions per minute and delivering air into a receiver at 80 pounds per square inch pressure. It will be seen that the sum of all the pressures in the divisions of the card amount to 541, which divided by the number of division measurements, 15, = 36 pounds per square inch as the mean pressure of the whole stroke. The usual practice is to divide the card into ten parts, but we have used fifteen, which gives a more satisfactory result; and even twenty parts gives a truer mean pressure. By comparing the mean pressure from the indicator card with the mean theoretical pressure in column 6 of Table XVII., which for 80 pounds gauge pressure is 43.88 pounds, it will be seen that a difference of 7.88 pounds exists, which is due to the absorption of heat by the walls of the air cylinder, clearance, and a possible leakage. It will also be seen that the isothermal mean pressure in column 7, Table XVII., for 80 pounds gauge pressure is theoretically 27.37 pounds, and the difference from the mean pressure of the indicator card is 8.63 pounds, so that with these figures the loca-

tion of the terminals of the adiabatic and isothermal curves can be established, and from which the actual efficiency of the compressor can be found for the speed at which it was running when the card was taken. For this card the speed was 50 revolutions per minute, which was but two-thirds the speed due to its full work. It may be noted here that the mean pressure due to the curve only, is $\frac{287}{11.8} = 24.3$ pounds, and that the mean pressure for isothermal compression due to the curve only for 80 pounds terminal is $27.37 - .155 \times 80 = 14.97$ pounds. The

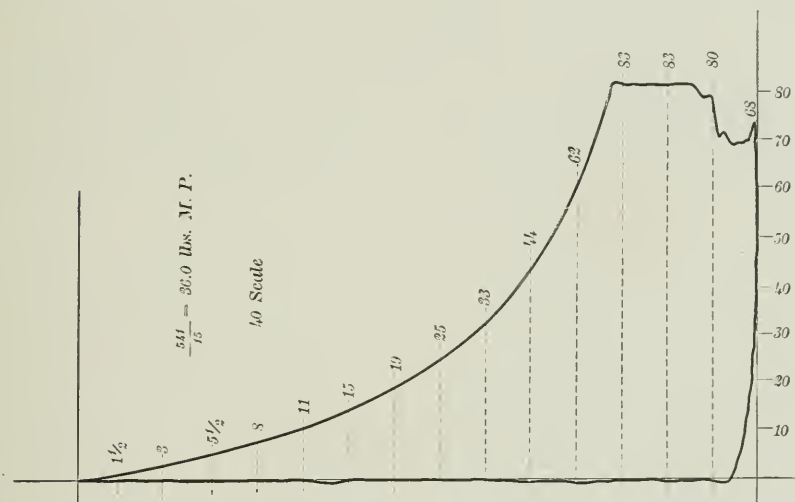


FIG. 47.—THE INDICATOR CARD.

difference $24.30 - 14.97 = 9.33$ represents the difference of the terminals of the actual and the isothermal curves in pressure terms. The mean pressure due to a perfect adiabatic compression, by Table XVII., column 6, for 80 pounds gauge pressure would be 43.88 pounds, and for isothermal compression 27.37 as per column 7, same table; their difference $16.51 - 9.33 = 7.18$, the mean of which is 35.62, a little less than shown on the measured card. This indicates the fact that the compressor by its slow speed absorbed less than one-half the heat generated by compression as indicated by the numbers 9.33 and 7.18; on the other hand the indicator card shown at Fig. 46 appears to

have been taken from a quick or normal speed of the compressor, and shows the actual compression curve considerably above the mean, only about one-third of the heat of compression being absorbed during the stroke of compression.

The falling-off of the line of delivery at the top of the cards indicates in part the absorption of heat from the air and the relief of the valve opening to the receiver pressure, which is always found to be from one to three pounds less than the compression pressure on the card.

THE STEAM AND AIR CARD.

In Fig. 48 is illustrated a combined steam and air indicator card, showing the reason for and answer to the oft-repeated question as to how it is possible to compress air to 80 or 100 pounds

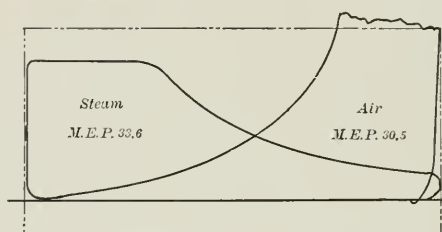


FIG. 48.—STEAM AND AIR CARD.

pressure with 60 pounds or less steam pressure with equal-sized cylinders. The reason is plainly shown in the comparative areas of the steam and air card, and from the computed mean engine pressure of each from actual measurement for pressures which show enough excess of power in the steam card to overcome the friction of the compressor and give it the required motion. The M. E. P. of the air card divided by the M. E. P. of the steam card shows 90 per cent efficiency, or that 10 per cent of the power of the steam used has been absorbed in the moving parts pertaining to both cylinders. In many of the best designed compressors, the difference shown in the steam and air cards has ranged from 5 to 6 per cent. What is made up in

the air card by high pressure is represented in the steam card by greater volume. It will be noticed that the central points of pressure in each card do not coincide, and that the minimum pressure in the steam cylinder occurs at the moment of maximum pressure in the air cylinder. This condition would check the operation of an air compressor but for the retaining power of the fly-wheel, the momentum of which carries the air piston to the end of its stroke, thus equalizing the motion of all the moving parts of a compressor. This condition is due to the high-pressure impulse of the steam piston being transmitted to the fly-wheels, in which it is stored and given out during the high-pressure work of the air piston.

The fly-wheel does more than this: its weight gives uniformity of motion to the compressor, so much to be desired in a continuously moving machine.

Chapter XI.

ACTUAL WORK OF THE COMPRESSOR

ACTUAL WORK OF THE COMPRESSOR.

No compressor of the piston type of modern construction can produce the conditions required by the theoretically adiabatic or isothermal lines in columns 6 and 7 in Table XVII. The mean pressure practically is always between these two lines, and in most compressors runs nearer to the adiabatic than to the isothermal line; and also varies in the same compressor with the speed and the efficiency of the water-jacket. In a high-speed compressor the mean pressure nears the adiabatic line, while with a slow speed and rapid cold-water circulation in the jacket it is possible to obtain a mean less than half the difference of the adiabatic and isothermal curves, time being a considerable element in fixing the curve of compression. It is only with compressors of the old Dubois and Francois type with water injection and water-filled clearance, and the hydraulic compressor of Sommeiller, that the isothermal line was nearly or quite reached; and later with the hydraulic pit compressors of the Frizell and Taylor type has it been possible to reach the full line of isothermal compression, and even under differences in temperature of the air and water, to produce a condition of compression of air and its delivery below the atmospheric temperature.

In Table XVIII. we have endeavored to show the practical operation of air compression with a single compression from 5 to 120 pounds by intervals of 5 pounds gauge pressure, with an assumed absorption of four-tenths of the heat of compression. In column 2 of the table the mean pressure for full stroke is obtained from six-tenths of the difference between the isothermal and adiabatic mean pressures found in columns 6 and 7, Table XVII., added to the isothermal mean pressure in column 7.

TABLE XVIII.—OF THE MEAN PRESSURE AND THE RELATIVE LOAD OF COMPRESSION AND DELIVERY IN TERMS OF THE MEAN PRESSURE OF THE WHOLE LOAD, FOR THE ACTUAL OPERATION OF A COMPRESSOR AT MEDIUM SPEED WITH AMPLE WATER CIRCULATION IN THE JACKET OF CYLINDER AND HEADS, DUE TO THE ESTIMATED ABSORPTION OF $\frac{1}{10}$ OF THE HEAT OF COMPRESSION FROM 60° F.

Gauge pressure, pounds.	Mean pressure for full stroke.	Pressure due to delivery in part of the whole stroke.	Mean compression of curve in part of the whole stroke.	Point of stroke when pressure is reached.	Temperature of discharge from 60° F.
1	2	3	4	5	6
5	4.49	3.92	0.57	0.785	87°
10	8.29	6.53	1.76	.665	112
15	11.54	8.43	3.11	.562	130
20	14.44	9.90	4.54	.495	148
25	17.05	11.10	5.95	.444	164
30	19.49	12.12	7.37	.404	178
35	21.73	12.98	8.75	.371	192
40	23.85	13.72	10.13	.343	204
45	25.81	14.40	11.41	.320	216
50	27.69	15.00	12.69	.300	227
55	29.48	15.56	13.93	.283	238
60	31.17	16.38	14.79	.273	247
65	32.79	16.64	16.15	.256	257
70	34.36	17.42	16.94	.242	266
75	35.84	18.52	17.32	.231	275
80	37.28	19.60	17.68	.221	283
85	38.67	20.57	18.10	.213	292
90	40.03	21.67	18.36	.204	300
95	41.35	22.64	18.71	.197	307
100	42.60	23.70	18.90	.189	314
105	43.80	24.48	19.32	.184	321
110	44.99	25.33	19.66	.178	329
115	46.20	26.30	19.90	.173	335
120	47.43	27.27	20.16	.168	342

Column 3 is obtained from six-tenths of the difference of the points of stroke in columns 4 and 5, Table XVII., for adiabatic and isothermal compression, added to the point of stroke for isothermal compression, column 5, and the sum multiplied by the pressure in column 1, which is equal to the part of the whole mean pressure due to delivery. Column 4 is equal to the part of the whole mean pressure due to the curve of compression only, and is found by column 2 — column 3 = column 4. Column 5 is the assumed point of stroke, found by adding six-tenths of the difference of the adiabatic and isothermal points of stroke in columns 4 and 5 in Table XVII., and the isothermal point of stroke in column 5 of the same table. Column

6 represents the temperature of the air from the compressor delivery valves, when four-tenths of the heat of compression from 60° F. has been absorbed by the cooling appliances and walls of the cylinder, and is obtained from column 3, Table XVI., -60° F. $\times \frac{6}{10}$ of this increase of temperature and 60° added to the product.

THE WORK OF AIR COMPRESSION.

It is often desired to find the amount of mechanical work which air receives during compression only, and also the work of the whole stroke of a piston for isothermal and adiabatic compression; we therefore illustrate in Fig. 49 an isothermal indicator card with the area of compression only, shaded to give to the eye a comprehensive comparison with the work of delivery shown by the rectangle following the point of compression stroke.

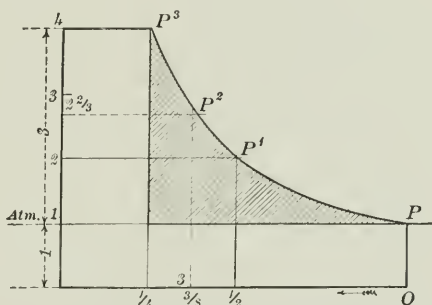


FIG. 49. — ISOMETRICAL CARD.

The curve of compression as represented in the diagram is that of a hyperbola, one of the properties of which is that the areas of the rectangles contained by the horizontal and vertical ordinates from the several points in the curve as at P , P^1 , P^2 , P^3 , are always the same, that is, all the pressures and volumes products (p, v), absolute rectangles, are equal in area; as further explained in the article on isothermal compression. Then for the work of compression from atmospheric or normal pressure (14.7) to any desired pressure, the increments of compression to the end of the stroke become a numerator in the fraction of the whole stroke, and their quotient becomes the ratio of which the hyperbolic logarithm multiplied by the pressure of the normal atmosphere upon a square foot equals the foot-

pounds required for compression. Thus, for compressing one cubic foot of air from atmospheric pressure to two atmospheres, we have $\frac{P}{P} = \frac{29.4}{14.7} = 2$, the hyperbolic logarithm of which is $.6931 \times 2,116.8 = 1,467.15$ foot-pounds per cubic foot of air compressed isothermally from atmospheric pressure to 14.7 pounds per square inch.

For any number of pounds pressure the ratio is obtained in the same way, viz., say for 75 pounds gauge pressure, $\frac{P}{P} = \frac{89.7}{14.7} = 6.1$ as given in column 3, Table XVII. The hyperbolic logarithm of 6.1 = 1.8083 $\times 2,116.8 = 3,827.8$ foot-pounds. Then $\frac{3,827.8}{33,000} = .116$ of a horse power, theoretical, to compress one cubic foot of air per minute to 75 pounds gauge pressure; to which must be added the friction of the compressor.

The foot-pound work isothermally per pound of air is obtained by multiplying the foot-pounds for one cubic foot by the number of cubic feet in a pound at atmospheric temperature; thus at 62° in Table XV., 13.141 cubic feet = 1 pound, and $13.141 \times 3,827.8 = 50,301$ foot-pounds.

Analyzing the isometrical card, Fig. 49, for the work due to compression only, and the work due to delivery as shown on the diagram; we find the whole work at 4 atmospheres absolute or 44.1 pounds gauge pressure to be as follows; then $\frac{4}{1} = 4$ hyp. log. = $1.3863 \times 2,116.8 = 2,934.5$ foot-pounds per cubic foot, and $44.1 \times 144 = 6,350.4 \times .25$ stroke = 1,587.6 foot-pounds in delivering 1 cubic foot of free air when compressed isothermally to 44.1 pounds per square inch gauge pressure. Then $2,934.5 - 1,587.6 = 1,346.9$ foot-pounds expended in compression only, for 1 cubic foot of free air at 44.1 pounds gauge pressure.

Adiabatic compression reaches a much higher theoretical work value, while the actual work of compression has an inter-

mediate work value depending upon the amount of heat absorption by the walls of the compressor.

In Fig. 50 is shown the theoretical card of adiabatic compression for 4 atmospheres absolute, 44.1 pounds gauge pressure, and in the shaded part the comparative work due to the curve of compression only, while the work of delivery is represented in the unhatched rectangle.

The formula for the work of compression for the complete stroke of a compressor is derived from the difference in temperature multiplied by the mechanical equivalent of air at constant pressure, $Mcp = 184.7$. Then $T_2 - T \times 184.7 = W$, the work. The difference in temperature may be obtained by the difference of absolute temperatures in column 2, Table XVI., and the mechanical equivalent for

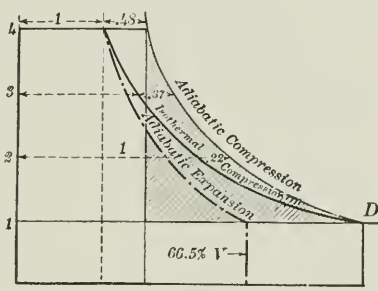


FIG. 50.—ADIABATIC CARD.

air is derived from the Joule equivalent multiplied by the specific heat of air; $778 \times .2375 = 184.7$.

In the case of the diagram Fig. 50, the work of compression of one pound of air from 60° F. temperature to 4 atmospheres absolute or 44.1 pounds per square inch gauge pressure will be $T_2 - T$, or $t - T$ as in column 2, Table XVI., or by the formula used for that column as before stated. The absolute temperature, $779 - 521 = 258^\circ \times 184.7 = 47,652.6$ foot-pounds per pound of free air. Then for the work per cubic foot of free air at 60° F. divide the number of foot-pounds per pound by the number of cubic feet of free air in Table XV. at 60° per pound of air. Then $\frac{47,652.6}{13.1} = 3,637$ foot pounds and $\frac{3,637}{33,000} = .1102$

of a horse power per cubic foot, to which must be added the proportional friction of the compressor. The work of compression due to delivery and to the compression curve separately is of interest. The point of stroke of the piston at which the

pressure is reached may be taken from column 4, Table XVII., for gauge pressure, or may be computed by the ratio of the absolute pressures from the formula, $\log. \frac{p^m}{p} = \frac{v_1}{v}$ and $\frac{1}{\log. \text{index}}$ = the point of stroke. As, for example, $\frac{58.8}{14.7} = 4$, the ratio for the absolute pressures.

The common log. for 4 is $0.60206 \times .711 = 0.42806$, the log. index of which is 2.68, and $\frac{1}{2.68} = .373$, the point of stroke from the terminal when full pressure is reached.

The whole number of foot-pounds when divided by the volume of one pound of air in cubic feet, for the temperature of the free air taken into the compressor, equals the foot-pounds per cubic foot. Then $\frac{47,652.6}{13.1} = 3,637.6$ foot-pounds per cubic foot of free air at 60° F. compressed to 4 atmospheres or 44.1 gauge pressure; and as the mean pressure for 44.1 is 28.9 pounds per square inch, and the point of stroke for the full stroke is .373 from the terminal, then $44.1 \times .373 = 16.45$, which is the proportion of the mean pressure due to delivery.

Then $\frac{28.9}{16.45} = 1.756$, the ratio of the foot-pounds due to delivery, to the total foot-pounds per pounds of air. Then $\frac{3,637}{1.756} = 2,071$ foot-pounds for the delivery, and $3,637 - 2,071 = 1,566$ foot-pounds due to the adiabatic compression curve of the card.

This method can be applied to the actual work of the compressor by using the relative pressures in columns 2, 3, and 4 in Table XVIII., which are based on actual conditions of a compressor in which four-tenths of the heat of compression is absorbed during compression.

Table XIX. has been computed by the formula and examples on page 167 of the work of isothermal compression for column 2 for pressures of every 5 pounds as in column 1. Column 3 has been computed by the formula and examples on page 169 of the

work of adiabatic compression, and column 4 represents the actual foot-pound work of compression per cubic foot of free air in compressors that absorb four-tenths of the heat due to compression, and has been obtained from six-tenths of the difference of columns 2 and 3 added to the isothermal foot-pound work in column 2.

TABLE XIX.—FOOT-POUNDS OF WORK REQUIRED FOR COMPRESSING AIR. THEORETICAL FOR COLUMNS 2 AND 3, AND FOR THE ACTUAL CONDITIONS WITH PARTIAL COOLING IN COLUMN 4 AS FOUND IN TABLE XVIII. FOR ONE-STAGE COMPRESSION.

Pressure in pounds.	Foot- pounds per cubic foot, isothermal.	Foot- pounds per cubic foot, adiabatic.	Foot- pounds per cubic foot, actual.	Pressure in pounds.	Foot- pounds per cubic foot, isothermal.	Foot- pounds per cubic foot, adiabatic.	Foot- pounds per cubic foot, actual.
1	2	3	4	1	2	3	4
5	619.6	649.5	637.5	55	3,393.7	4,188.9	3,870.8
10	1,098.2	1,192.0	1,154.6	60	3,440.4	4,422.8	4,029.8
15	1,488.3	1,661.2	1,592.0	65	3,577.6	4,645.4	4,218.2
20	1,817.7	2,074.0	1,971.4	70	3,706.3	4,859.6	4,398.1
25	2,102.6	2,451.6	2,312.0	75	3,828.0	5,063.9	4,569.5
30	2,353.6	2,794.0	2,617.8	80	3,942.9	5,259.7	4,732.9
35	2,578.0	3,111.0	2,897.8	85	4,051.5	5,450.0	4,891.6
40	2,780.8	3,405.5	3,155.6	90	4,155.7	5,633.1	5,042.1
45	2,966.0	3,681.7	3,395.4	95	4,254.3	5,809.3	5,187.3
50	3,136.2	3,942.3	3,619.8	100	4,348.1	5,981.2	5,327.9

Other equations or formulas may be used for obtaining the foot-pounds of work required to compress air to any desired pressure. For example, the adiabatic volume

$$\frac{V}{v} = \frac{\text{the adiabatic vol.}}{\text{initial vol.}} \text{ and } \frac{V^{.406}}{v} = \frac{t}{T}.$$

Then the ratio of the absolute volumes raised to the power of .406 logarithmically is equal to the ratio of the temperatures due to the equivalent compression; also $\frac{V}{v} = \left(\frac{p}{P}\right)^{.711}$ and $\left(\frac{p}{P}\right)^{.29} = \frac{t}{T}$ are also logarithmic ratios from which the pressure is derived from the volumes and the temperature from the relative pressures.

Then for working the equation $\frac{V^{.406}}{v} = \frac{t}{T}$ we may use the Table XVII.; in column 2 we find the adiabatic ratio of 14.7

gauge pressure by interpolation to be 1.64, the log. of which is $0.21484 \times .406 = 0.087225$, the index of which is 1.222, which is equal to the ratio of the absolute temperatures as found in column 2, Table XVI., or $\frac{639^\circ}{522^\circ} = 1.2222^\circ$.

Again we have $\left(\frac{p}{P}\right)^{.711} = \frac{V}{v}$ as explained before.

For the work of compression we have

$$W = \frac{1.406}{.406} d R T \left(\frac{P^{.29}}{P} - 1 \right).$$

In which $\frac{1.406}{.406} = 3.438$, a constant. $d R$ = the difference of the foot-pound equivalents of specific heat at constant pressure, $M c p = 184.77$, and the specific heat at constant volume $M c v = 131.6$, which = 53.17, and T = the normal absolute temperature from $60^\circ \text{ F.} = 522^\circ$.

For example, to obtain the foot-pound work for adiabatic compression from 60° F. to two absolute atmospheres, or 14.7 pounds gauge pressure, we have as per equation above $3.438 \times 53.17 \times 522 \times \left(\frac{29.4^{.29}}{14.7} - 1 \right)$ = the foot-pounds for one pound of free air, and this product divided by 13.1 = the foot-pounds of work per cubic foot. The operation will then be for the last term of the equation $\frac{29.4}{14.7} = 2$, the logarithm of which is $0.30103 \times .29 = \log. 0.08729$, the index of which is 1.2225, and $1.2225 - 1 = .2225$. The total product will then be 21,231 foot-pounds per pound of air, and $\frac{21,231}{13.1} = 1,620$ foot-pounds per cubic foot of free air compressed from 60° F. to 14.7 pounds gauge pressure. This differs slightly in amount from the method of computation by temperatures on account of not carrying out fully the decimal system.

The saving in foot-pound work by compressing air that is moist even to saturation has been demonstrated, by experiments

made in France by M. Mallard, to be $5\frac{1}{2}$ per cent at 3 atmospheres, $7\frac{1}{2}$ per cent at 4 atmospheres, 11 per cent at 5 atmospheres, and 12 per cent at 7 atmospheres. This should be observed as an advantage in foot-pound work by compressing air in rainy or foggy weather.

Chapter XII.

MULTI-STAGE AIR COMPRESSION

MULTI-STAGE AIR COMPRESSION.

THE great range of pressures through which compressed air is used, calls for pressures varying from 1 pound to 3,000 or more pounds per square inch; but the greatest field of its work is found between 50 and 100 pounds gauge pressure. Even at 100 pounds the greatest economy of production is found in the two-stage effect, which eliminates to a large degree the heat-resisting power acquired during the second half of the piston stroke in a single-stage compressor. For higher pressures the economy of two-stage compression is largely increased up to 500 pounds, and with three-stage compression up to 1,000 pounds, and with four-stage compression up to 3,000 pounds.

The great heat generated by single compression to high pressures is apparent by referring to Table XVI., where it will be seen that the single-compression temperature for a pressure of 200 pounds reached 673° F., which is above the melting-point of lead, and will fire woodwork. The effect of such great heat on the packing and lubricants of a compressor are apparent; hence the necessity for a two-stage process with intercooling when compressing air to above 100 pounds pressure. The heat of single-stage compression is graphically shown in the diagram Fig. 45, where the temperatures are shown for different free air intakes at 0° , 60° , and 100° F., and the heat of compression temperatures at the pressures of atmospheres up to 21 and of pounds gauge pressure up to 294. Of course the absorption of heat by the cylinder walls modifies the temperature somewhat, but the fire pump before described shows that pressures from air at the ordinary temperature of a room will ignite combustibles at above 350 pounds pressure.

The introduction of water into the cylinder as formerly prac-

tised has had but little practical effect, and unless introduced in quantities to keep down the temperature does not add to heat economy, and in large quantities adds to the cost of work. The manner and time of injection greatly affect its usefulness in cooling the air, so that if drawn in by the suction of the piston its spraying effect is lost by its contact with the cool incoming air, and the spray can only wet the walls and piston at best. If it is forced in as a fine spray at the moment that the compression has raised the temperature enough to be absorbed by the water, say through the last half of the stroke, it requires power and the operation of a pump, at a cost that seriously affects the economy of the water-injection system. Besides the entanglements appertaining to this method of obtaining compressed air at moderately high pressures, the compressed air is loaded with moisture which is not all dropped in the receiver, in active operations, but is carried along the transmission pipes in a misty or saturated condition, and becomes a nuisance in the exhaust of operating machines. The uncertainty of the quantity of water entering a cylinder with a quick-working piston is a source of danger from concussion, and finally the wear and tear of water-injection cylinders from the inability to obtain pure water has been one of the principal causes of the abandonment of this class of compressors by experienced builders.

TWO-STAGE COMPRESSION.

The practice of two-stage compression for moderate pressures, say to 100 pounds, has been long in use in the compressors of the Norwalk Iron Works, with a fair claim for economy over the increased friction from the second cylinder. For pressures above 100 pounds further compounding becomes necessary, as a matter of both economy and safety. Safety being in some cases an important element in eliminating as far as possible the liability of explosive effect from high temperature and its effect upon the oil of lubrication, this will be discussed further on.

In Fig. 51 is shown an outline card of two-stage compres-

sion to 75 pounds in which the maximum pressure of over 80 pounds was reached in order freely to deliver the air through exit valves of restricted area. The depressed inlet curve of the second-stage card shows one of the losses in multiple compression, which is due to the small area of the intercooler, its connections, valves, and to the shrinkage of volume by the intercooler, which, if its capacity is not equal to isothermal cooling, causes a loss in the work of the second cylinder. With cooling receivers of large capacity the continuous working value of the second cylinder rises to its proper function, and the inlet card

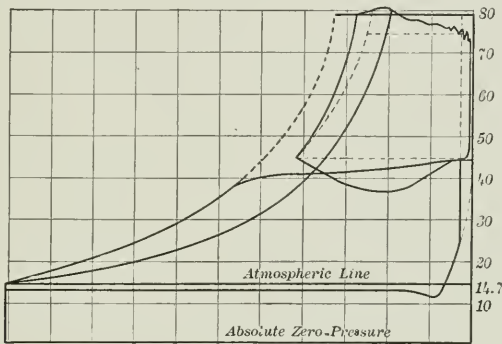


FIG. 51.—TWO-STAGE CARD.

lines come more near to the delivery line of the first-stage cylinder. The possibilities of economy may then rise from 4 per cent to about 15 per cent of the work lost by heat in two-stage compression, above the isothermal work.

The heat loss by one-stage compression to 80 pounds from 60° F. is equal to $\frac{5.259 - 3.942}{3.942} = .334$ per cent of the foot-pound

work of isothermal compression, theoretical; the figure being from the adiabatic and isothermal columns in Table XIX. The actual loss may be much less in the most efficient water-jacketed head compressors, as shown in a comparison of columns 2 and 4 in Table XIX. Taking the figures for 80 pounds from these columns we have $\frac{4.732 - 3.942}{3.942} = .204$ per cent loss in foot-pounds of the work of isothermal compression.

The following table will serve to illustrate the large saving that it is possible to effect by compounding. This table gives the percentage of work lost by the heat of compression, taking isothermal compression, or compression without heat, as a base.

TABLE XX.—POWER LOST BY ONE, TWO, AND FOUR STAGE COMPRESSION.

Gauge pressures.	One stage.	Two stage.	Four stage.	Gauge pressures.	One stage.	Two stage.	Four stage.
	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.
60.....	30.00	13.38	4.65	1,000.....	96.80	37.00	16.90
80.....	34.00	15.12	5.64	1,200.....	106.15	40.00	17.45
100.....	38.00	17.10	8.00	1,400.....	108.00	41.60	17.70
200.....	52.35	23.20	9.01	1,600.....	110.00	42.90	18.40
400.....	68.60	29.70	12.40	1,800.....	116.80	44.40	19.12
600.....	83.75	32.65	15.06	2,000.....	121.70	44.60	20.00
800.....	90.00	35.80	16.74				

In columns 2, 3, and 4 no account is taken of jacket cooling, it being a well-known fact among pneumatic engineers that water jackets, especially cylinder jackets, though useful and perhaps indispensable, are not efficient in cooling, especially so in large compressors. The volume of air is so great in proportion to the surface exposed, and the time of compression so short, that little or no cooling takes place. Jacketed heads are useful auxiliaries in cooling, but it has become an accepted theory among engineers that compounding or stage compression is more fertile as a means of economy than any other system that has yet been devised. The two and four stage figures in this table (columns 3 and 4), are based on reduction to atmospheric temperature 60° F. between stages. This is an important condition, and in order to effect it much depends on the intercooler. In this device we have a case of jacket cooling which in practice has been found to be efficient where engineers specify intercoolers of proper design. While cooling between stages we may split the air up into thin layers and thus cool it efficiently in a short time, a condition not possible during compression. This splitting-up process should be done thoroughly, and while it adds to the cost of the plant to provide efficient coolers, it pays in the end.

Referring again to the table, we learn that when air is compressed to 100 pounds pressure per square inch in a single-stage compressor without cooling, the heat loss may be thirty-eight per cent. This condition, of course, does not exist in practice, except perhaps at exceedingly high speeds, as there will be some absorption of heat by the exposed parts of the machine. It is safe, however, to say that in large air compressors that compress in a single stage up to 100 pounds gauge pressure, the heat loss is thirty per cent. This, as shown in the table, may be cut down more than one-half by compounding or compressing in two stages, and with three stages this loss is brought down to eight per cent theoretically, and perhaps to three or five per cent in practice. As higher pressures are used, the gain by compounding is greater.

The practical effect of compounding, however, does not result in any material economy, unless the air is thoroughly cooled between the stages. Hot air in the cylinder of an air compressor means a reduction in the efficiency of the machine, because there is not sufficient time during the stroke to cool thoroughly by any available means. Water jacketing, the generally accepted practice, does not effect thorough cooling. The air in the cylinder is so large in volume that but a fraction of its surface is brought in contact with the jacketed parts. Air is a bad conductor of heat and takes time to change its temperature. The piston, while pushing the air toward the head, rapidly drives it away from the jacketed surfaces, so that little or no cooling takes place. This is especially true of large cylinders, where the economy effected by water jackets is considerably less than in small cylinders. Leaks through the valves or past the piston will explain many indicator cards, and until something better than a water jacket is devised it is well to seek economy in air compression through compounding.

In the case of high pressures, that is, from 500 to 3,000 pounds, it is essential to resort to compounding on the most economic lines by water-jacketing to the furthest extent and

to intercooling to a possible normal temperature, and for from 2,000 to 3,000 pounds the four-stage operation becomes imperative.

THE INTERCOOLER IN STAGE COMPRESSION.

One of the most important adjuncts in the economy of compressing air by stages to any desired pressure is the intercooler.

For its best or most economical effect upon the work of a compound or multi-stage compressor, it should cool the passing

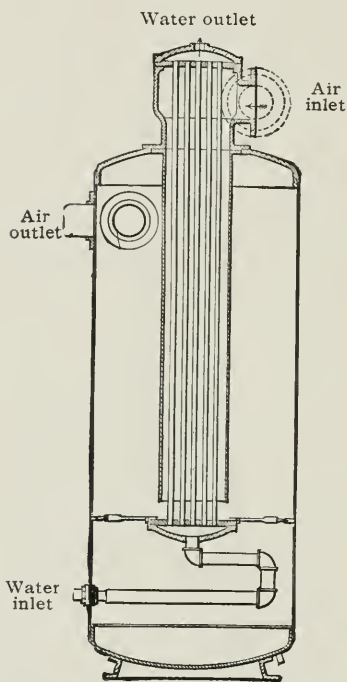


FIG. 52. - THE SERGEANT INTERCOOLER.

air between each of the compression stages to its normal temperature, and, if colder water is available, to a temperature as much as possible below the normal temperature. We illustrate in Fig. 52 one of the most approved combinations of intercooler and receiver, the Sergeant type, in which the heated air, direct from the compressor, passes into an upper opening, and down between a large number of small tinned copper tubes, held vertically in a sort of chimney. The air finally emerges into the shell portion of the intercooler and is free to travel through the top to the outlet tube. The smaller tubes mentioned terminate

at either end in plates, into which they are expanded. The cooling water enters through the lower pipe and is forced upward through the cooler tubes, and finally emerges at the water outlet at the top. The water tubes are set so close together that they divide the incoming stream of air into thin sheets and bring it into very intimate contact with the cooling surface. As stated, the air is caused to enter at the top and pass downward, while

the cooling water enters at the bottom and passes upward. This is the accumulating principle upon which all successful liquid-air apparatus have been constructed.

A properly designed intercooler should reduce the temperature of the compressed air to its original point; that is, to the temperature of the intake air. It can do even more than this, especially in winter, when the water used in the intercooler is of low temperature. A simple coil of pipe submerged in water is not an effective intercooler, because the air passes through the coil too rapidly to be cooled in the core, and such intercoolers do not sufficiently split up the air to enable it to be cooled rapidly. This splitting up of air is an important point. A nest of tubes carrying water and arranged as described, so that the air is forced between and around the tubes, is an important point in an efficient form of intercooler. If the tubes are close enough together and are kept cold, the air *must* split up into thin sheets while passing through. Such devices are naturally expensive; but first cost is a small item when compared with the efficiency of the compressor, measured in the coal and water consumed.

Receiver-intercoolers are more efficient than those of the common type, because the air is given more time to pass through the cooling stages, and because of the freedom from wire-drawing in the intake of the next cylinder, which may take place in intercoolers of small volumetric capacity.

See Fig. 54 for illustration of intercooler of the Rand Drill Co., and further on for that of the Norwalk Compressor.

AFTERCOOLERS.

AFTERCOOLERS are in some installations as important as intercoolers. An aftercooler serves to reduce the temperature of the air after the final compression. In doing this it serves as a dryer, reducing the temperature of air to the dew-point, thus abstracting moisture before the air is started on its journey. In cold weather, with air pipes laid over the ground, an after-

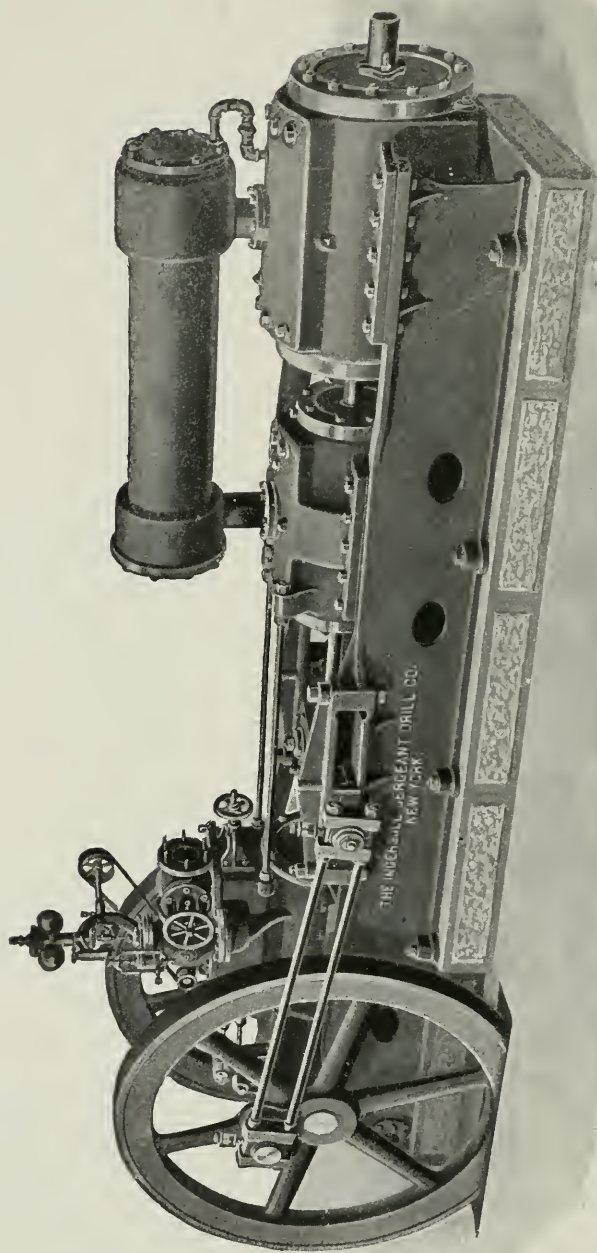


FIG. 53.—INGERSOLL-SERGEANT "STRAIGHT-LINE" AIR COMPRESSOR.

With compound cylinders and horizontal intercooler. For pressures up to 120 lbs.

cooler may prevent accumulation of frost in the interior walls of the pipes, for where the hot compressed air is allowed to cool gradually, the walls of the pipe in cold weather act like a surface condenser, and moisture may be deposited on the inside for the same reason that we have frost on the inner side of a window pane. In using these aftercoolers, and also intercoolers, it is good practice to allow from 8 to 10 cubic feet of free air

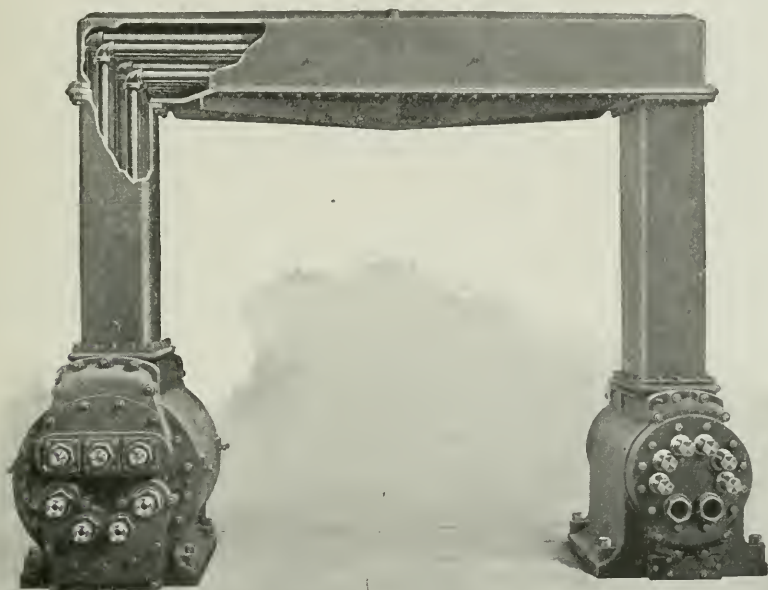


FIG. 54.—THE RAND INTERCOOLER.

per minute for each square foot of cooling surface. Further, an allowance of 1 pound of water for each 2 cubic feet of free air should be made.

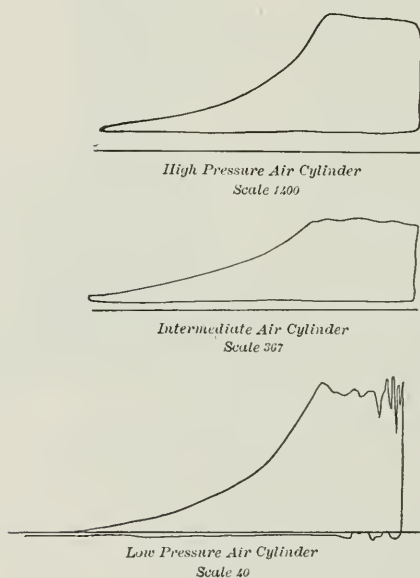
In Fig. 53 we illustrate the Ingersoll-Sergeant steam actuated "straight-line" compound air compressor with an inter-cooler attached directly to the top of the cylinders. The inter-cooling cylinder or drum contains a water-circulating coil of pipes around which the air passes from the low to the high pressure cylinder. The pipe surface being so large, the air is cooled to

its normal temperature or possibly below when cold water is available.

In Fig. 54 is illustrated the intercooler of the Rand Drill Company, which by its form and position allows of a very large amount of cooling surface to be utilized in the transfer of air from the low to the high pressure cylinder with a minimum amount of retardation by friction, thus giving to a two-stage system of compression a high efficiency.

One of the principal advantages of two-stage compression over single-stage compression is found in the reduction of loss due to the heat of compression, and this represents a saving in power, since the resistance due to compression is directly proportional to changes in temperature. Other reductions in losses

are found in reduction of clearance and strains and in a more uniform air resistance.



THREE-STAGE AIR COMPRESSION.

The three cards, Fig. 55, represent in reduced scale the low-pressure, intermediate, and high-pressure cards of a three-stage compressor for compressing air to 2,000 pounds gauge pressure for a pneumatic gun battery at Fort Winfield Scott, San Francisco, Cal. The

discharge from the low-pressure cylinder was at 75 pounds, intermediate at 375 pounds, and the high-pressure at 2,000 pounds. The temperatures of the incoming air were brought down to slightly below normal by efficient intercoolers—the normal temperature being 75° F., the intermediate inlet show-

FIG. 55.—THREE-STAGE AIR COMPRESSION.

ing 73° F., and the high-pressure inlet 69° F. The large area of the receivers seems to have been a source of economy, as shown in the inlet lines of the cards. The cylinders, being all thoroughly water-jacketed, gave the following temperatures in the discharge pipe: Low pressure 320° F., intermediate 289° F., high pressure 358° F., the adiabatic differences being 100° , 264° , and 522° respectively. This is a most interesting showing of the value of proper intercooling.

The combined card equivalent to the three cards Fig. 55 is shown in Fig. 56, in which the cubic feet per revolution is scaled at the bottom of the card and the pressure for each stage is shown at the right of the vertical leg. The delivery lines of these cards show a faultless arrangement of air connections and valve areas.

FOUR-STAGE AIR COMPRESSION.

In Fig. 57 we present a combined air card of four-stage compression to 2,500 pounds per square

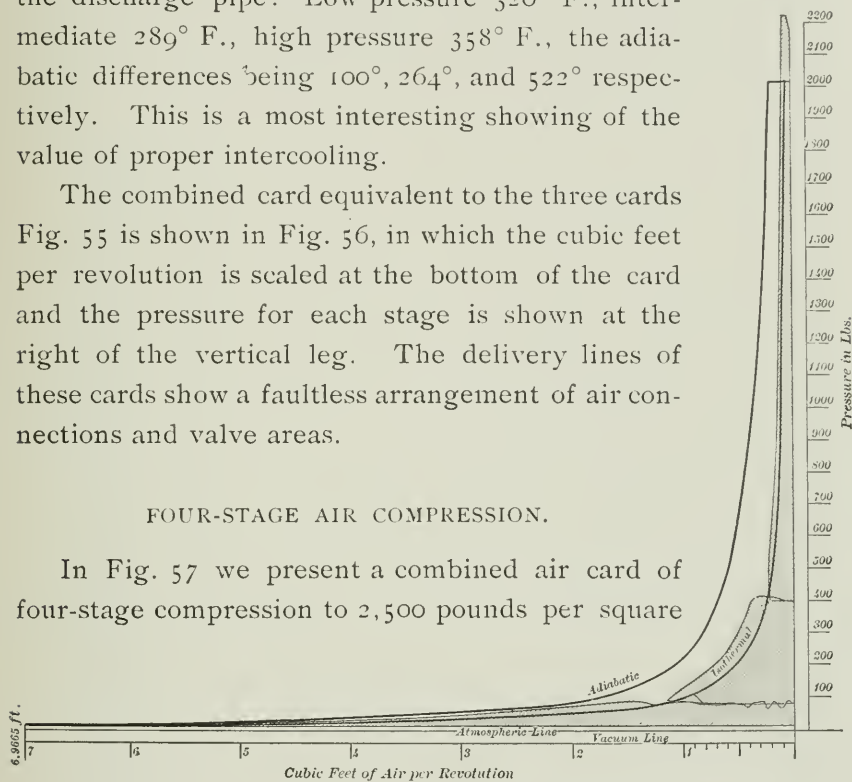


FIG. 56.—THREE-STAGE COMPRESSION CARD.

inch. It represents the conditions derived from the actual cards taken from a four-cylinder single-acting compressor of the Ingersoll-Sergeant Drill Company, operated by two non-condensing Corliss engines; the individual steam cards of which, with the air cards, are shown in Fig. 58. The steam cylinders were 18 by 36 inches, direct connected.

The low and first intermediate air pistons were connected to one engine, the second intermediate and high-pressure air pistons to the other engine; the engines being connected on one

shaft with cranks at right angles. The four single-acting air cylinders were $21\frac{1}{4}$, 9, 7, and $3\frac{1}{2}$ inches diameter respectively, by 36-inch stroke.

All the air cylinders were water-jacketed and provided with intercoolers of the Ingersoll-Sergeant type. The first intercooler has a capacity of 9 cubic feet as against 7.241 cubic feet in the low-pressure cylinder, with a cooling surface 112 square feet. The second intercooler was 1.8 cubic feet as against 1.32 cubic feet in the first intermediate, with 60 square feet of cooling surface. The third intercooler was .7 cubic foot as against .57 cubic foot in the second intermediate air cylinder, with 35 square feet of cooling surface; while the after-cooler was of 1.6 cubic feet capacity with 45 square feet of cooling surface. The uniform lines of air intake, as shown on the separate cards, are of interest and are due to the large intercooler capacity in its relation to the following cylinder. For this relation we find that the first intercooler had 6.8 times the volume of the second compressing cyl-

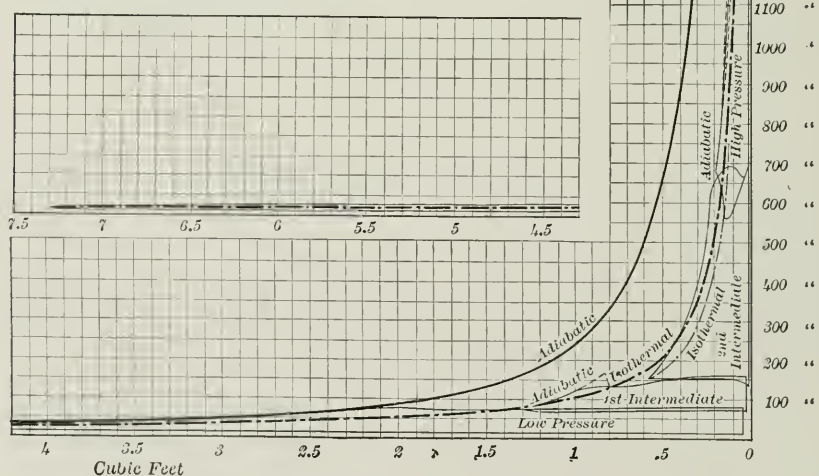


FIG. 57.—FOUR-STAGE AIR COMPRESSION CARD.

inder, and the second intercooler had 3.2 times the volume of the following or third compressing cylinder, while the third intercooler had a volume of 3.9 times that of the high-pressure cylinder.

The compressor engines made 58 revolutions per minute, compressing 419 cubic feet of free air from atmospheric pressure at 75° F. to 2,500 pounds pressure, and delivering the air

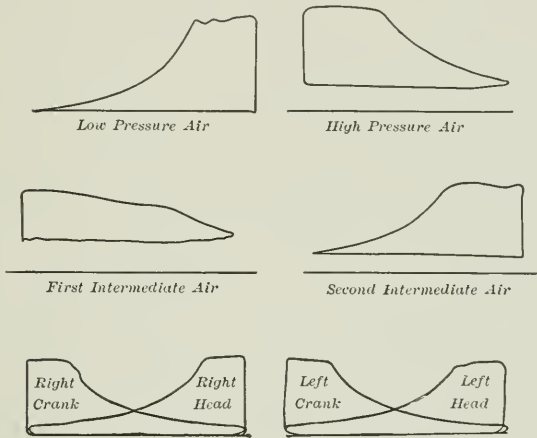


FIG. 58.—SEPARATE AIR CARDS AND STEAM CARDS

from the high-pressure cylinder at 230° F., and from the after-cooler at normal temperature.

The horse power developed at the maximum air pressure was 204 I. H. P. in the engines and 168.5 in the compressor, showing an efficiency of .826 for the friction losses in the entire plant. The temperature of the air throughout the stages is of interest, and from the record, the air entered the first stage at 74° F., was delivered at 176° , entered the second cylinder at 90° , was delivered at 142° , and finally delivered from the high-pressure cylinder at 230° F. The figures also show that 2 cubic feet or possibly more free air can be compressed to 2,500 pounds per square inch per indicated horse power. We have no test for general efficiency under full working pressure of this four-stage compressor; but tests made while running from 135 to 170 atmospheres gave an efficiency

of about 65 per cent, and from the work of filling the receivers from 1 to 171 atmospheres, an average efficiency of 68 per cent; so that in regular work at full load the efficiency may be anticipated to average about 63 per cent.

In tests made by representatives from the Cornell University, the several efficiencies of the apparatus are given as follows: Mechanical efficiency, 90.4 per cent; efficiency of compression, 88.9 per cent; volumetric efficiency, 89.34 per cent. The product of these is 71.8 per cent, a considerably higher figure than either of those obtained from calculations based on the receiver pressure. We are unable to account for the difference except on the supposition that the indicated work of the air cylinders was not accurately measured. All indicator cards are liable to certain percentages of error, and there is an unusually large probability of error in the measurement of the indicated work in the second intermediate and the high-pressure air cylinders, since the pistons of the indicators used in taking the cards were only of $\frac{1}{4}$ and 0.1 inch diameter, respectively; and the nominal scale of the springs was, respectively, 250 and 1,250 pounds to the inch.

The method of computing the efficiency of the apparatus by comparing directly the work done in the steam cylinders with the work of storing the air in the receiver, measured by the volume of the receiver and the difference between the pressure at the beginning and end of the test, eliminates the errors of measuring the work done in the air cylinders by means of indicator diagrams. By this method it is not at all necessary to take diagrams from the air cylinders, although such diagrams are valuable for determining approximately the proportions of work done in the several cylinders, the value of the water jackets and intercoolers in reducing the total work of compression, the mechanical efficiency of the apparatus, and the so-called efficiency of compression, or the ratio of the indicated work in the air cylinders to the theoretical work of isothermal compression.

It is fair to state that the efficiency obtained above is based on tests made when the plant was newly set up and running under conditions in some respects less favorable than those which may obtain when it has been longer in service. Considering this fact and the very high pressure to which the air is raised, the figures of efficiency above attained appear very creditable to the designers and builders of this remarkable compressor.

THE FOOT-POUND WORK OF MULTIPLE-STAGE AIR COMPRESSION.

Using the following formulas, we have for the first stage,

$$W = P_0 V \frac{y}{y-1} \left(\frac{P}{P_0}^{\frac{y-1}{y}} - 1 \right) \quad (1.)$$

and for the second stage,

$$W = P_0 V \frac{y}{y-1} \left(\frac{P}{P_1}^{\frac{y-1}{y}} \right) + \left(\frac{P^2}{P_1}^{\frac{y-1}{y}} - 2 \right) \quad (2.)$$

when the air is cooled to normal temperature between the stages, and for computation, $P_0 = 2,116.8$, the pressure of the free atmosphere per square foot. $V = 1$ cubic foot or any number of cubic feet. $\frac{y}{y-1} = \frac{1.406}{.406} = 3.438$. $\frac{P}{P_0}$ = the logarithmic ratio of the normal and the assumed absolute pressure of compression. $\frac{y-1}{y} = \frac{.406}{1.406} = .29$. -1 and -2 are the integers of the index of the logarithmic product of the pressure ratio and its exponent.

For a two-stage compression to 100 pounds gauge pressure and to 50 pounds for the first stage, the computation is as follows:

First stage, $2,116.8 \times 1 \times 3.438 = 7,277.55$. $\frac{P}{P_0} = \frac{64.7}{14.7} = 4.401$ the ratio; the logarithm of which is $0.643551 \times$ by the exponent $.29 = 0.186629$, the index of which $= 1.537 - 1 = .537$, which $\times 7,277.55 = 3,908$ foot-pounds per cubic foot. To this

should be added the compressor friction and deducted the value in foot-pounds of the cooling effect of the cylinder.

For the second stage we have $2,116.8 \times 1 \times 3.438 = 7,277.55$ as before and the index of the first compression logarithm 1.537, to which must be added the index of the log. of the ratio of the second stage, which is $\frac{P_2}{P_1} = \frac{114.7}{64.7} = 1.7727 = \log. 0.24861 \times .29 = 0.072097$, the index of which is 1.181, to which add the index of the first stage $1.537 = 2.718$, and $2.718 - 2 = .718 \times 7,277.55 = 5,228$ foot-pounds per cubic foot, and .158 of a horse power per cubic foot, to which should be added the compressor friction, say 5 per cent, and deduct for cylinder cooling, say 8 per cent, which will be about 3 per cent to be deducted; or the theoretical work will nearly cover the losses and gains.

TABLE XXI.—HORSE-POWER DEVELOPED TO COMPRESS 100 CUBIC FEET OF FREE AIR, FROM ATMOSPHERE TO VARIOUS PRESSURES.

Gauge pressure, pounds.	One-stage compression D. H. P.	Gauge pressure, pounds.	Two-stage compression D. H. P.	Four-stage compression D. H. P.
10	3.60	60	11.70	10.80
15	5.03	80	13.70	12.50
20	6.28	100	15.40	14.20
25	7.42	200	21.20	18.75
30	8.47	300	24.50	21.80
35	9.42	400	27.70	24.00
40	10.30	500	29.75	25.90
45	11.14	600	31.70	27.50
50	11.90	700	33.50	28.90
55	12.07	800	34.90	30.00
60	13.41	900	36.30	31.00
70	14.72	1,000	37.80	31.80
80	15.94	1,200	39.70	33.30
90	17.06	1,600	43.00	35.65
100	18.15	2,000	45.50	37.80
		2,300 .....	....	39.06
		3,000 .....	....	40.15

For a three-stage compression to, say, 1,000 pounds gauge pressure, we have from the value of the first three terms as before $7,277.55 \times$ by the sum of the indices for the logarithms of the ratios for each previous stage + the index of the last stage - 3, the integers for three stages. The third stage will be $\frac{P_3}{P_2} = \frac{1,014.7}{114.7} = 8.846 \log. 0.946747 \times .29 = 0.274556$, index

$1.8815 + 2.718 = 4.5995 - 3 = 1.5995 \times 7,277.55 = 11,640$ foot-pounds per cubic foot, or .352 of a horse power per cubic foot.

The compression of 100 cubic feet of free air per minute and the work developed in horse power has been tabulated from the formulas before given for one, two, and four stage compression. It represents very nearly the actual work of compression in first-class compressors, allowing for cylinder cooling, intercooling, and friction, which last partially neutralizes the cylinder-cooling effect. Table XXI.

The economy in power saved by two-stage compression for even as low a pressure as 60 pounds is very evident by inspection of this table, which shows for sixty pounds a saving of 14.5 per cent and for 100 pounds 17.8 per cent. The saving for 1,000 pounds pressure of a four-stage compression over a two-stage is 18.8 per cent.

Chapter XIII.

THE EXPANSION OF COMPRESSED AIR AND THE WORK OF THE MOTOR

THE EXPANSION OF COMPRESSED AIR AND THE WORK OF THE MOTOR.

THE expansion of compressed air does work in a cylinder on the same lines as in the work of compression. The curve of expansion from normal temperature for compressed air is adiabatic in the negative sense, for by compression the pressure and work are cumulative, while by expansion they are depletive,

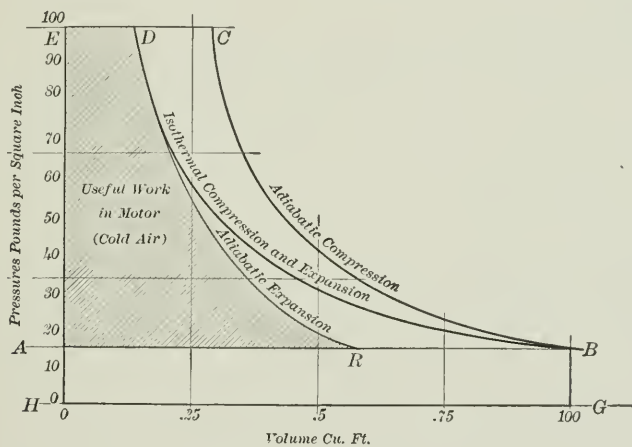


FIG. 59.—EXPANSION CARD.

as shown by the card Fig. 59, in which the three radial lines of air pressure and work are shown. The curves are all hyperbolic in form, and for expansion are subject to an inversion of the equations and formulas used in compression. The theoretical equations for the expansion of air when no heat is absorbed by the motor cylinder are the same as for compression with the principal terms inverted. Therefore the 1.406 powers of the specific volumes are inversely proportional to the corresponding absolute pressures and temperatures.

We have then the proportion $v^{1.406} : v_1^{1.406} :: p_1 : p$ and $p v^{1.406} = p_1 v_1^{1.406}$, v_1 and p_1 being the greater volume and pressure; also $\frac{v^{1.406}}{v_1^{1.406}} = \frac{p_1}{p}$. Then using logarithms, $1.406 \times \log. \frac{v}{v_1} = \log. \frac{p_1}{p}$ and $\log. \frac{p}{p_1} = 1.406 \times \log. \frac{v_1}{v}$, or $\frac{p}{p_1} = \frac{v_1^{1.406}}{v^{1.406}}$.

If we assume the initial volume $v_1 = 1$, and the original tension or pressure $p_1 = 1$ atmosphere, we have for the pressure or tension p when the air has expanded to twice its volume, or $v = 2 v_1$, without loss of heat (adiabatic), $1.406 \times \log. 2 = \log. \frac{1}{p}$. Then, for example, $1.406 \times \log. 0.30103 = \log. 0.423248 = \log. \frac{1}{p}$. Then $\log. 0.423248$ index = 2.65 and $\frac{1}{p} = \frac{1}{2.65} = .377$ atmosphere.

For temperature of expansion we have,

$$\left(\frac{v}{v_1}\right)^{0.406} = \frac{T_1}{T} = \frac{\text{absolute reduced temperature}}{\text{absolute normal temperature}}.$$

Then for a specific volume v_1 expanded to 2 volumes from a temperature of $60^\circ \text{ F.} = 522^\circ$ absolute, we have $\left(\frac{2 v_1}{v_1}\right)^{0.406} = \frac{462 + 60^\circ}{462 + t}$ and $\log. 2 = 0.30103 \times 0.406 = \log. 0.122218$, index 1.325 = the ratio of the respective temperatures. Then $522 \times 1.325 = 691.6 - 522 = 169.6^\circ$, the drop in temperature due to the expansion of one volume to two volumes from 60° F. For the terminal pressure from the adiabatic expansion of compressed air in an engine or motor cylinder, we have the formula

$$\left[\frac{p}{1^{1.406}}\right] - P = \text{terminal pressure},$$

in which p is the absolute initial pressure or gauge pressure plus 14.7, and P the absolute atmospheric pressure, 14.7. $\frac{1}{R}$ = the ratio of expansion obtained by dividing 1 by the cut-off expressed in tenths of the stroke of the piston. Thus for a cut-off of $\frac{3}{10}$ or .3, $\frac{10}{3} = 3.333$ the ratio, the logarithm of which must

be multiplied by the exponent 1.406. The index of the logarithmic product becomes a divisor of the absolute initial pressure, from the quotient of which the atmospheric pressure must be deducted for the terminal pressure. For example, for $\frac{3}{10}$ cut-off and 60 pounds gauge pressure, we have $\frac{10}{3} = 3.333 \log.$
 $0.522835 \times 1.406 = 0.735106$, the index of which is 5.434; then $\frac{74.7}{5.434} = 13.7 - 14.7 = -1$. The terminal pressure being one pound less than atmospheric pressure.

By a series of terminal pressures computed by the above formula, a card may be made indicating the terminal pressures of the adiabatic curve for any number of divisions so arranged that the cut-off may represent an even number of divisions, and the sum of all the divisions divided by the number will equal the mean pressure.

As an example we illustrate this method by a card Fig. 60 detailed for $\frac{3}{10}$ cut-off at 100 pounds gauge pressure.

The approximate mean of the expansion from the third to the fourth division will be as follows: The ratio of expansion for the terminal is $\frac{4}{3} = 1.333 \log. 0.12483 \times 1.406 = 0.17551$, index 1.498. Then $\frac{114.7}{1.498} = 76.56 - 14.7 = 61.8$ and $\frac{61.8 + 100}{2} = 80.9$ the mean pressure due to the expansion of the fourth space. The next terminal will be $\frac{5}{3} = 1.666 \log. 0.221675 \times 1.406 = 0.311675$, index 2.05, and $\frac{114.7}{2.05} = 55.9 - 14.7 = 41.2$. Then $\frac{41.2 + 61.8}{2} = 51.5$ the mean pressure of the fifth space, and so on through the ten spaces; the whole aggregating $\frac{527.94}{10} = 52.79$, the mean pressure of the card with a terminal of 6.58 pounds, which approximates nearly to the figures given as

computed from the ratios in the 3d and 7th columns of Table XXIII. These computations and the values given in Table XXIII. are theoretical, and take no account of the clearance in the cylinder and ports and of the absorption of heat by the air from the motor cylinder. It is noted that the cylinder of a motor is much colder than the outer air when compressed air at atmospheric temperature is used, and heat is being constantly absorbed by the cylinder and given to the expanding air. It will be readily understood that the walls of a motor cylinder,

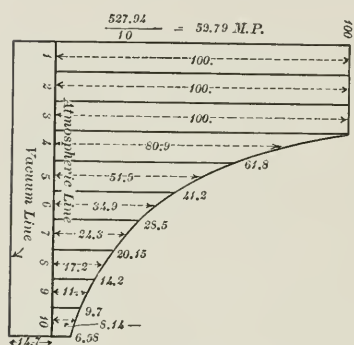


FIG. 60.—EXPANSION CARD.

as soon as normal running conditions are established, absorb heat from the incoming air at atmospheric temperature until a moment after the cut-off, when the condition becomes reversed and the cold expanding air receives heat from the walls of the cylinder in an increasing degree until the exhaust takes place, when, if under a terminal pressure, the tempera-

ture of the contents of the cylinder suddenly drops to the point due to the total expansion from the working pressure to atmospheric pressure, less the amount of heat absorbed at full pressure or given to the expanding air during the expulsion of the cold air on the return stroke of the piston. These amounts are small in their effect upon motor efficiency, and can be entirely eliminated by warming the motor cylinder—just the opposite of the treatment of a compressor cylinder for increasing its efficiency. The clearance in a motor cylinder adds to its mean pressure at the expense of the relative volume of the stroke at the cut-off. The volume of the clearance also increases the volume due to the nominal cut-off, varying with the cut-off volume.

In the following table is given the actual cut-off due to the various percentages of the clearance in motor cylinders for the nominal cut-off as given in column 1.

For example, let the cylinder stroke be 10 and the clearance .07 per cent, cut-off $\frac{3}{10}$, then $10 \times .07 = .7 + 10 = 10.7$, the actual volume of cylinder and clearance. Then the sum of the ratios of the cut-off and clearance divided by the actual volume of the cylinder and clearance equals the actual clearance, $3 + .7 = \frac{3.7}{10.7} = .3457$ the actual clearance. In this manner the following table of nominal cut-off percentage of clearance and actual cut-off has been computed. The rule serves for any cut-off and clearance.

TABLE XXII.—EXCESS OF CUT-OFF DUE TO THE PERCENTAGE OF CLEARANCE FOR THE NOMINAL CUT-OFF IN COLUMN 1, FOR COMPRESSED-AIR MOTORS.

Nominal cut-off.	PERCENTAGE OF CLEARANCE.						
	.03	.04	.05	.06	.07	.08	.10
0.10	0.126	0.135	0.143	0.151	0.159	0.167	0.182
.12	.146	.154	.162	.170	.177	.185	.200
.14	.165	.174	.181	.189	.196	.204	.218
.16	.184	.193	.200	.207	.215	.222	.236
.18	.204	.212	.219	.226	.233	.240	.254
.20	.223	.231	.238	.245	.252	.259	.273
.22	.243	.251	.257	.264	.271	.277	.291
.24	.262	.270	.276	.283	.290	.296	.309
.25	.272	.279	.286	.293	.299	.305	.318
.26	.281	.289	.295	.302	.308	.315	.327
.28	.301	.308	.314	.321	.327	.333	.345
.30	.320	.327	.333	.340	.346	.352	.364
.32	.340	.346	.352	.359	.364	.370	.382
.34	.359	.366	.371	.378	.383	.389	.400
.36	.378	.385	.390	.396	.402	.407	.418
.38	.398	.404	.409	.415	.420	.425	.436
.40	.417	.423	.429	.434	.439	.444	.455
.42	.437	.442	.448	.453	.458	.462	.473
.44	.456	.462	.467	.472	.477	.481	.491
.46	.475	.481	.486	.490	.495	.500	.509
.48	.495	.500	.505	.509	.514	.518	.527
.50	.514	.519	.524	.528	.533	.537	.546
.52	.534	.538	.543	.547	.551	.555	.564
.54	.554	.558	.562	.566	.570	.574	.582
.56	.573	.577	.581	.585	.589	.593	.600
.58	.593	.596	.600	.604	.607	.611	.618
.60	.612	.615	.619	.623	.626	.630	.637
.62	.632	.634	.638	.642	.645	.648	.655
.64	.651	.654	.657	.661	.664	.667	.673
.66	.670	.673	.676	.679	.682	.685	.691
.68	.690	.692	.695	.698	.701	.703	.709
.70	.709	.711	.714	.717	.720	.722	.727
.72	.729	.731	.733	.736	.738	.740	.745
.74	.748	.750	.752	.755	.757	.759	.763
.75	.758	.760	.762	.764	.766	.768	.772

In Table XXIII. are given the theoretical conditions in regard to the pressures and temperatures of compressed air when expanding in the cylinder of a motor engine, to which corrections must be made for clearance by adding the additional amount to the cut-off as per Table XXII. for various percentages of clearance, for a definite ratio of expansion, from which other ratios for the pressures and temperatures may be computed from the formulas given for each column in Table XXIII.

TABLE XXIII.—RATIOS OF PRESSURES AND TEMPERATURES DUE TO EXPANSION OF COMPRESSED AIR IN A MOTOR CYLINDER, THEORETICAL.

Cut-off.	Ratio of expansion $\frac{1}{\text{cut-off.}}$	Ratio of mean to total absolute pressure, $P \times \text{Ratio} - P =$ mean pressure.	Ratio of mean to total absolute pressure during expansion only, $P \times \text{Ratio} - P_1$	Ratio of initial to final temperature, $T \times R = T_2 =$ absolute temperature of exhaust.	Ratio of initial to final absolute temperature due to cylinder expansion only, $T \times R = T_1$	Ratio of initial to final absolute pressures for ratio of expansion, $P \times R - P =$ final pressure.
1	2	3	4	5	6	7
0.10	10.00	0.2493	0.1659	0.3908	0.5131	0.0391
.12	8.33	.29 3	.1935	.4210	.5410	.0535
.14	7.14	.3293	.2201	.4484	.5657	.0628
.16	6.25	.3665	.2458	.4735	.5880	.0758
.18	5.55	.4020	.2708	.4968	.6084	.0894
.20	5.00	.4360	.2950	.5186	.6273	.1037
.22	4.54	.4685	.3186	.5392	.6448	.1186
.24	4.16	.4996	.3416	.5586	.6613	.1341
.25	4.00	.5147	.3529	.5680	.6692	.1420
.26	3.84	.5295	.3641	.5772	.6768	.1501
.28	3.57	.5580	.3861	.5949	.6915	.1666
.30	3.33	.5854	.4077	.6119	.7055	.1836
.32	3.12	.6116	.4288	.6282	.7188	.2010
.34	2.94	.6367	.4496	.6439	.7315	.2189
.36	2.78	.6608	.4700	.6591	.7438	.2373
.38	2.63	.6838	.4900	.6738	.7555	.2561
.40	2.50	.7 58	.5097	.6881	.7668	.2752
.42	2.38	.7269	.5291	.7019	.7777	.2948
.44	2.27	.7470	.5481	.7154	.7883	.3148
.46	2.17	.7662	.5670	.7285	.7985	.3351
.48	2.08	.7845	.5855	.7412	.8084	.3558
.50	2.00	.8019	.6 38	.7537	.8180	.3768
.52	1.92	.8185	.6218	.7658	.8274	.3982
.54	1.85	.8342	.6396	.7777	.8365	.4200
.56	1.78	.8492	.6572	.7893	.8453	.4420
.58	1.72	.8633	.6745	.8007	.8540	.4644
.60	1.667	.8767	.6919	.8119	.8624	.4871
.62	1.61	.8893	.7 86	.8228	.87 6	.5101
.64	1.56	.9 11	.7254	.8335	.8787	.5335
.66	1.51	.9123	.7419	.8441	.8866	.5571
.68	1.47	.9227	.7583	.8544	.8943	.5810
.70	1.429	.9324	.7745	.8646	.9018	.6052
.72	1.39	.9414	.79 6	.8746	.9092	.6297
.74	1.35	.9497	.8 64	.8844	.9165	.6545
.75	1.333	.9536	.8143	.8893	.9200	.6669

In these columns R is the ratio as in column 2, or a ratio assumed by the addition for clearance percentage as given in Table XXII. Account should be taken of the heat absorbed by a motor cylinder when operated by compressed air at atmospheric temperature. When air is reheated before entering a motor cylinder so as to exhaust at near atmospheric temperature, the theoretical conditions will not be materially affected.

The formulas from which Table XXIII. has been computed are:

For column 2, $\frac{1}{\text{cut-off}} = \text{ratio of expansion.}$

For column 3, the formula is $\frac{2.451 \times \left[1 - \left(\frac{1}{R} \right)^{.408} \right]}{R} + \frac{1}{R} =$ ratio of mean pressure during the whole stroke, and $(p \times \text{ratio}) - P = \text{mean pressure.}$ The first terms of the equation as shown below become $\frac{.9512331}{3.333} = .2854$, adding $\frac{1}{R} = .3 = .5854$ the ratio for .3 cut-off as in column 3.

For column 4, $\frac{2.451 \times \left[1 - \left(\frac{1}{R} \right)^{.408} \right]}{R - 1} = \text{ratio of mean to total absolute pressure during expansion only; for which the value is obtained by multiplying the absolute initial pressure by the ratio and subtracting the atmospheric pressure. } p \times \text{ratio} - P = \text{mean pressure.}$ As an example, for computing from this formula, we assume a motor running with 50 pounds gauge pressure and $\frac{3}{10}$ cut-off. The formula may then be written

$$\frac{2.451 \times \left[1 - \left(\frac{1}{3.33} \right)^{.408} \right]}{3.33 - 1}.$$

The exponential ratio must be obtained by logarithms. Log. 3.333 = 0.522835 $\times$.408 = log. 0.213316 index of which is 1.634 and $\frac{1}{1.634} = .6119$ and $1 - .6119 = .3881 \times 2.451 = .9512331$ and $\frac{.9512331}{2.333} = .4077$, the ratio as found in column 4.

Column 5. $\left(\frac{1}{R}\right)^{.408}$ the ratio being for $\frac{3}{10}$ cut-off 3.333 as before, $\log. \times$ by the exponent gives $\frac{1}{1.634} = .6119$, as found in column 5. Then if a motor is running with 50 pounds gauge pressure and at 60° F. atmospheric temperature, or 520° absolute, and $(520 \times .6119) - 460 = -142^\circ$ F. theoretical, modified by the effect of the clearance and heat absorbed from the outer atmosphere through the cylinder. In this case the final pressure at exhaust as per ratio in column 7 will be $64.7 \times .1836 = 11.87 - 14.7 = -2.83$ pounds, which shows that a $\frac{3}{10}$ cut-off is not the most economical point unless the clearance is sufficient to bring the final pressure to the atmospheric line or enough above to compensate for engine friction.

Column 6. $\left(\frac{1}{R}\right)^{.29}$ is the ratio of temperature for initial and final pressures, and is obtained by the same method as for column 5.

Then for $\frac{3}{10}$ cut-off as above $(520^\circ \times .7055) - 460^\circ = -93.2^\circ$; the temperature when the pressure reaches the atmospheric line.

Column 7. $\frac{\left(\frac{1}{R}\right)^{.408}}{R}$ is the ratio of initial and final absolute pressures for the given ratio of volume $\left(\frac{1}{R}\right)^{.408}$ which is the logarithmic ratio as in column 5, divided by the ratio in column 2, and gives the terminal pressure in the cylinder; as, for example, for 50 pounds gauge pressure and $\frac{3}{10}$ cut-off $(64.7 \times .1836) - 14.7 = -2.83$ or nearly 3 pounds negative pressure.

Now, for example, take the clearance effect into consideration for the same pressure and cut-off. We find that for a clearance of 5 per cent the nominal cut-off will be advanced to a real cut-off of .333 and $\frac{1}{.333} = 3$ the ratio. Then $\left(\frac{1}{3}\right)^{.408}$

$\log .477121 \times .408 = 0.194665$, index of which is 1.565 and $\frac{1}{1.565} = .639$ and $\frac{.639}{3} = .213$, the ratio of the absolute initial and final pressures. Then $(64.7 \times .213) - 14.7 = -1$, the terminal pressure.

Thus we find that at 60 pounds gauge pressure $\frac{3}{10}$ cut-off with 5 per cent clearance will give a terminal pressure of + 1.2 pounds, which is a very economical point of cut-off for this pressure and clearance.

TABLE XXIV.—MEAN AND TERMINAL PRESSURES IN AN AIR ENGINE OR MOTOR. THEORETICAL AND NOT INCLUDING CLEARANCE. WITH RATIOS FOR EACH CUT-OFF.

Cut-off.	Pressures.	GAUGE PRESSURES, POUNDS.						RATIO. $P \times R - P.$
		50.	60.	70.	80.	90.	100.	
$\frac{2}{10}$	Mean	13.5	17.8	22.2	26.5	30.9	35.3	.4360
	Terminal ..	- 8.0	- 7.0	- 6.0	- 4.9	- 3.9	- 2.8	.1037
$\frac{1}{4}$	Mean	18.6	23.7	28.9	34.0	39.2	44.3	.5147
	Terminal ..	- 5.6	- 4.1	2.7	- 1.3	+ .1	1.6	.1420
$\frac{3}{10}$	Mean	23.2	29.0	34.9	40.7	46.6	52.4	.5854
	Terminal ..	- 2.6	- 1.0	+ .8	2.6	4.5	6.3	.1836
$\frac{3.5}{100}$	Mean	28.0	34.7	41.2	47.8	54.5	61.0	.6608
	Terminal ..	0.0	2.3	4.6	6.9	9.2	11.5	.2281
$\frac{4}{10}$	Mean	31.0	38.0	45.1	52.1	59.3	66.3	.7058
	Terminal ..	3.1	5.8	8.6	11.4	14.1	16.9	.2752
$\frac{5}{10}$	Mean	37.2	45.2	53.2	61.2	69.2	77.3	.8019
	Terminal ..	9.6	13.4	17.2	21.0	24.7	28.5	.3768
$\frac{6}{10}$	Mean	42.0	50.8	59.5	68.3	77.1	85.9	.8767
	Terminal ..	16.8	21.7	26.5	31.4	36.3	41.2	.4871

The values in the above table are derived from the ratios in Table XXIII. and may be interpolated by using ratios in that table, or the formula by which they were computed for any required cut-off, to which the extensions for any percentage of clearance may be added from Table XXII.

THE WORK OF EXPANSION.

The work of expansion of air from any temperature to the zero of absolute temperature in foot-pounds has an intrinsic value measured by the mechanical equivalent of air at constant volume, $Mcv = 778 \times .1689 = 131.6$ foot-pounds per unit of heat. Then from 60° F. the absolute temperature is 520° F., and $520 \times 131.6 = 68,432$ foot-pounds.

From 32° F. it is $492^\circ \times 131.6 = 64,747$ foot-pounds.

By another formula, the atmospheric pressure P_0 multiplied by the volume of 1 pound of air in cubic feet at atmospheric pressure at any specific temperature, and the product divided by the ratio of the specific heats, γ , or $\frac{P_0 V_0}{.406}$ for the above temperature, the work will then be $\frac{2,116.8 \times 13.1}{.406} = 68,300$ foot-pounds.

In Table XV. are given the volumes of 1 pound of air at various temperatures. The variation in the values of the specific heat of air at constant pressure and at constant volume, assigned by different investigators, is the cause of the discrepancy in the results from the formulas of different authors; see article on specific heat and Table XIV.

For ascertaining the amount of foot-pound work of compressed air, expanding to atmospheric pressure from any initial pressure, we have the formula, $3 T \frac{P_0}{w t_0} \left[1 - \left(\frac{P}{P_0} \right)^{\frac{1}{\gamma}} \right] =$ foot-pounds of work per pound of air, adiabatic expansion.

For example, one pound of air at 2 atmospheres 29.4 pounds absolute pressure, 14.7 pounds gauge pressure, at 60° F., is computed from the following figured terms:

$$\frac{3 \times 520^\circ \times \frac{2,116.8}{.0807 \times 492^\circ} \left[1 - \left(\frac{14.7}{29.4} \right)^{\frac{1}{3}} \right]}{83,179} \times 1 - 3 \sqrt[3]{\frac{1}{2}} = \frac{1}{1.2599} = .788$$

$1 - .788 = .212 \times 83,179 = 17,634$ foot-pounds, and $\frac{17,634}{13.1} = 1,346$ foot-pounds per cubic foot.

For any other pressure, say 50 pound-gauge pressure. The sum of the first three terms is a constant, viz., 83,189, and the fourth term will be

$$\left[1 - \left(\frac{14.7}{64.7} \right)^{\frac{1}{3}} \right] = 1 - 3\sqrt[3]{\frac{1}{4.4}} = \frac{1}{1.64} = .609$$

and $1 - .609 = .391 \times 83,189 = 32,526.9$ foot-pounds per pound of air expanded from 50 pounds gauge pressure to atmospheric pressure. Then $\frac{32,526.9}{13.1} = 2,483$ foot-pounds per cubic foot.

The ratios of pressures and volumes from adiabatic compression and expansion may be obtained from the following

formulas, $\frac{P_1}{P} = \left(\frac{v}{v_1} \right)^{1.406}$ and $\frac{v}{v_1} = \left(\frac{P_1}{P} \right)^{0.71}$ in which P_1 and v_1 are

the greater pressures and volumes. Then, for example, for the relative volume of compression, say for two atmospheres absolute or any number of pounds absolute pressure, we have

$\frac{P_1}{P} = \left(\frac{14.7}{29.4} \right) = \left(\frac{1}{2} \right)^{.71} \log. 2 = 0.30103 \times .71 = 0.21373$, the index of which is 1.636 and $\frac{1}{1.636} = .617$, the ratio of compression

and expansion. Then assuming 1 pound of air 13.1 c', we have $13.1 \times .617 = 8.08$ cubic feet, the volume of 1 pound after adiabatic compression to 14.7 pounds gauge pressure, and $\frac{13.1}{.617} =$

21.2 cubic feet, the volume of 13.1 cubic feet of air at 14.7 pounds gauge pressure when completely expanded adiabatically from 14.7 pounds gauge pressure.

The formulas for the work of expansion vary slightly in their results as given by different authors. Using Professor Unwin's formula for foot-pounds of work (theoretical) for one pound of air, we have

$$\frac{y}{y-1} P v \left[1 - \left(\frac{p}{P_1} \right)^{\frac{y-1}{y}} \right] = 3.438 \times 2,116.8 \times 13.1 = 95,336$$

for the first three terms, and for an expansion from 3 absolute atmospheres 44.1, to atmospheric pressure 14.7,

$$\left[1 - \left(\frac{14.7}{44.1} \right)^{.29} \right] \text{ or in figures } \left[1 - \left(\frac{1}{3} \right)^{.29} \right].$$

Then $\frac{1}{3} \log. 3 = 0.477121 \times .29 = \log. 0.138365$, the index of which is 1.375 and $\frac{1}{1.375} = .7272$, and $1 - .7272 = .2728 \times 95.336 = 26,007$ foot-pounds for the work of one pound (13.1 cubic feet) of air expanding from 29.4 gauge pressure to atmospheric pressure; not including friction and lost work from leakage.

Another formula from Church's "Mechanics of Engineering," for the foot-pounds of expansion of 1 pound of free air compressed and used for work in a cylinder, is:

$3 T \frac{P_0}{.0807 t_0} \left[1 - \left(\frac{P}{p} \right)^{\frac{1}{3}} \right]$, in which the cube root of the pressure ratio is used as the exponent. Then for 30 pounds gauge pressure and $\frac{P}{p} = \frac{14.7}{44.7}$, T = absolute temperature of the working air, say 60° F. , and t_0 the absolute temperature of 32° F. The figures will then be

$$3 \times 520 \times \frac{2,116.8}{.0807 \times 492^\circ} \left[1 - \left(\frac{14.7}{44.7} \right)^{\frac{1}{3}} \right].$$

The product of the first three terms is $83,179 \times \sqrt[3]{\frac{1}{3.04}} = \frac{1}{1.448} = .6905$, and $1 - .6905 = .3095$. Then $83,179 \times .3095 = 25,743$ foot-pounds, the work of expansion of one pound of free air (13.1 cubic feet) at 60° F. from 30 pounds gauge pressure to atmospheric pressure. $\frac{25,743}{13.1} = 1,965$ foot-pounds per cubic foot.

In computing the practical work of expansion in a cylinder, the actual ratio of expansion is not due to the nominal ratio of the cut-off to the stroke, since expansion also takes place in the volume of the clearance by the amount of the piston clearance

and port area. As the nominal clearance is expressed in parts of 10, the percentage of the clearance is also expressed in parts of 10. Then the cut-off plus the clearance, divided by the cylinder volume plus the clearance, equals the actual cut-off, as per Tables XXII. and XXIII. and examples in their explanation.

Chapter XIV.

TRANSMISSION OF POWER BY COMPRESSED AIR

TRANSMISSION OF POWER BY COMPRESSED AIR.

THE use of compressed air for power purposes at a distance from the compressing plant is no longer a mooted subject of discussion. Successful use for even great distances has become a fact in practice, and its economy is no longer in doubt. More than twenty years ago the distribution of compressed air for power rental attracted attention, since which time it has made rapid strides in useful installations that are widespread; not only for public service, but for operating machines and tools in machine shops, factories, and our great constructive works.

For mining and drifting in tunnel work the transmission of compressed air for running drills and pumps has been long known as the leading method and the only safe and economical means of operating machinery underground and throughout the drifts and galleries to the deep headings of the modern mining system.

The conveying of compressed air for a few thousand feet had been long in use, and its convenience and economy could not be gainsaid; but when transmission for miles came to be considered, the question of loss of power had its period of discussion; now the doubts raised have been put to flight by the later practice and its accomplished facts.

The continuous compressed air line of ten and twenty miles has at last become an actuality, owing to the progress of manufacture of large pipe lines of great sustaining power, by which air at high pressure may be conveyed through pipe lines of suitable size to guarantee small loss from air friction. The apparent loss by friction may be slightly compensated by expansion of the volume at a lower delivery pressure, so that what it loses in pressure it gains in value; yet the fall in pressure in long pipe lines does involve a loss in transmission, as

shown by the loss of efficiency in the motor due to loss of initial pressure.

As compared with other means of transmitting power for great distances, air is always available and can be discharged from motors or pumps with a health-giving property in mines or in factories; it has peculiar advantages in underground work.

The success in the distribution of compressed air for power and refrigeration during the past twenty years in Paris, France, and later in England, Switzerland, and Germany, has set aside all doubts as to its utility and economy. For its work in a great city, it has no equal, as shown by the multiplicity of operations carried on in Paris by the compressed-air system as lately developed there. The compressed-air plant has now been increased to 24,000 horse power, having main pipe and distributing lines aggregating 140 miles in length, of which about 100 miles are used for power purposes alone, and 40 miles for the operation of pneumatic clocks. From the power mains the smaller distributing mains aggregate 20 miles in length, and supply 955 power consumers, and also 1,637 establishments in which compressed air is used for the operation of pneumatic clocks, of which there are about 7,000. Not only is compressed air used for small factory power and refrigeration, but it has become a most convenient power for elevators, for there are nearly two hundred passenger and freight elevators used throughout the mercantile district in which the air pipes are laid. A more detailed description of this interesting plant will be given further on.

It is truly strange, in view of the successful operation of a public supply of compressed air in Paris and other parts of Europe for the past twenty years, that our otherwise enterprising American cities, so noted for internal improvements, are still behind the age in the distribution of air power from central plants.

As to the loss of power by transmission through long lines, the tests made with the Paris plant have furnished us with the

best practical results. The average velocity in the mains of the Paris system for a length of main equal to 55,000 feet—about 10 miles—was found to be 20 feet per second, and the loss due to friction was 1.65 pound per mile. This for 10 miles would amount to 16.4 pounds loss in pressure, or about 18 per cent from an initial pressure of 92 pounds. This leaves a clean working pressure of 75 pounds at the end of the line, with higher pressures all along the line in a municipal distribution with one continuous pipe line. In the system of distribution as arranged in the Paris and Birmingham air plants, the drop in air pressure throughout the lines does not exceed 8 pounds.

In the planning of a compressed-air transmission system, especially for public service, a consideration of future wants in the first installation, by the laying of much larger-sized pipes than are required for present use, becomes a source of immediate economy in air-pressure loss, and will obviate some of the troubles and losses that are now felt in the Paris plants, which have been caused by the increased demand for air power when its convenience came to be recognized by the community. To summarize, air is in practice proving to be a fairly cheap and most convenient transmitter of power, allowing fine subdivision and transportation to remote points, with the crowning and unique quality of suffering no appreciable loss when held in storage. For intermittent service it is of great value, allowing widely varying speed of tools, dispensing with long lines of shafting and belts, giving free head-room, and increasing the shop-light as well as lessening the first cost of roof frames when they have not to carry shafting. The pipes require no coating; they radiate no heat, and therefore can be put in close corners without increasing the fire risk; their direction is readily changed in any plane without risk of pocketing or water-hammer, and leaky joints are not a nuisance or risk. In no case are exhaust pipes required, and in most, if not all cases, the exhaust adds to the men's comfort.

COMPRESSED AIR FLOWING IN PIPES.

When compressed air flows along a pipe there is necessarily a fall of pressure due to the resistance of the wall surface of the pipe, friction, and consequently the volume and velocity of the air increase along the length of the pipe in the direction of the motion. Generally, in compressed-air transmitting systems, the air is delivered into the mains at a temperature above that of the surrounding air, or of the earth in underground lines. The excess of heat is soon absorbed by the surrounding medium, and in long lines the transmission may be said to be isothermal. The loss of pressure is independent of any changes in temperature; it is directly proportional to the length of the pipe line and to the square of the velocity, and inversely as the diameter of the pipe. The gain in free air delivery by loss of pressure is nearly as the square root of the loss in pressure. From experiments made for friction in the long lines at the Mont Cenis tunnel it was found that the frictional loss in pressure was $0.0936 \frac{v^2 l}{d}$, in which v was the velocity in feet per second, l the length of pipe in feet, and d the diameter of the pipe in inches.

Other formulas were used in the experiments for obtaining the friction in long pipes in the Paris system, in which the velocity became a term in the equation, together with a coefficient of decreasing value with the increase in size of the pipe. Thus the coefficient c was assigned to vary as $.0027 \left(1 + \frac{3}{10d}\right)$, in which d is the diameter of the pipe in inches.

Using D'Arcy's coefficients for the actual diameters of wrought-iron pipe, we have the discharge in cubic feet of compressed air per minute under the terminal pressure from a pipe of any diameter and length with various initial and terminal pressures from the following equation: $D = c \sqrt{\frac{d^5 \times p - p_2}{w \times \text{length}}}$

in which d^5 is the fifth power of the actual diameter, $p - p_2$, the difference between the initial and final pressures, w the density of the compressed air at the initial pressure as in column 3, Table XXVI.; the length of the pipe line in feet.

In Table XXV. are given the nominal diameter of wrought-iron pipe of standard sizes, the actual diameter, the value of the coefficient c , and the value of the coefficient multiplied by the square root of the fifth power of the actual diameter, $c\sqrt{d^5}$, which will facilitate computation.

In Table XXVI., column 3, the weight of a cubic foot of compressed air is given for the pressures in column 1, multiplied by the ratio in column 2, or by the formula, $w = (.068 \times P) + 1 \times .0761$, where P is the initial gauge pressure in pounds per square inch at the receiver or entrance to the transmission pipe.

For any pressure not found in the tables the above formula may be used, as, for example, for 500 pounds gauge pressure $.068 \times 500 = 34 + 1 = 35 \times .0761 = 2.663$, the weight of 1 cubic foot of air at 500 pounds gauge pressure. This may also be obtained by the ratio of absolute compression $\times .0761$. $\frac{514.7}{14.7} = 35 \times .0761 = 2.663$, as before.

TABLE XXV.—OF NOMINAL AND ACTUAL DIAMETERS AND AREAS OF STANDARD WROUGHT IRON PIPE. COEFFICIENTS AND MULTIPLIERS FOR $c\sqrt{d^5}$ FOR DIFFERENT-SIZED PIPES.

Nominal diameter, inches.	Actual diameter, inches.	Actual area.	D'Arcy's coefficient c .	$c\sqrt{d^5}$.	Nominal diameter, inches.	Actual diameter, inches.	Actual area.	D'Arcy's coefficient c .	$c\sqrt{d^5}$.
1	2	3	4	5	1	2	3	4	5
1	1.048	0.8626	45.3	45.3	5	5.025	19.99	58.4	3,298.0
1¼	1.38	1.49	47.8	86.0	6	6.065	28.888	59.5	5,273.
1½	1.61	2.03	50.3	138.3	7	7.023	38.738	60.1	7,317.
2	2.067	3.356	52.7	297.	8	7.98	50.04	60.7	10,988.
2½	2.46	4.78	54.4	537.	9	8.937	62.73	61.2	14,872.
3	3.026	7.388	56.1	876.	10	10.019	78.839	61.8	19,480.
3½	3.56	9.83	56.9	1,304.	12	12.00	113.098	62.1	30,926.
4	4.026	12.73	57.8	1,856.	14	14.25	159.485	62.3	45,690.
4½	4.5	15.93	58.1	2,492.	16	16.4	211.24	62.6	64,102.

For the amount of free air corresponding with any given pressure multiply the gauge pressure by the ratio in column 2, Table XXVI., or the volume of discharge for any terminal pressure as found by the formula $D = c \sqrt{\frac{d^5 \times P - P_2}{w \times l}} \times \text{column 2}$, or by the ratio of compression as above explained.

TABLE XXVI.—GAUGE PRESSURES AND CORRESPONDING WEIGHT OF A CUBIC FOOT OF COMPRESSED AIR AND ITS SQUARE ROOT.

Gauge pressure.	Ratio of volumes. $\frac{P}{P}$	W weight of one cubic foot at pressure, column 1.	$\sqrt{\text{weight, column 3.}}$	Gauge pressure.	Ratio of volumes $\frac{P}{P}$	W weight of one cubic foot at pressure, column 1.	$\sqrt{\text{weight, column 3.}}$
1	2	3	4	1	2	3	4
0	1.00	0.0761	0.276	55	4.74	0.3677	0.600
5	1.34	.1020	.319	60	5.08	.3866	.622
10	1.68	.1278	.358	65	5.42	.4125	.642
15	2.02	.1537	.392	70	5.76	.4383	.662
20	2.36	.1796	.424	75	6.10	.4642	.681
25	2.70	.2055	.453	80	6.44	.4901	.700
30	3.04	.2313	.481	85	6.78	.5160	.718
35	3.38	.2572	.507	90	7.12	.5418	.736
40	3.72	.2831	.532	95	7.46	.5677	.753
45	4.06	.3090	.556	100	7.80	.5936	.770
50	4.40	.3348	.578				

As, for example, what amount of free air can be discharged through a 4-inch pipe 5,000 feet long; initial pressure 100 pounds, terminal pressure 75 pounds? Then, as per above formula and per Table XXV., column 5, $c \sqrt{d^5} = 1,856$, $\sqrt{P - P_2} = \sqrt{25} = 5 \times 1,856 = 9,280$, and from column 4, Table XXVI., $\sqrt{w} = .77$, $\sqrt{5,000} \text{ feet} = 70.71$; then $70.71 \times .77 = 54.44$, and $\frac{9,280}{54.44} = 170.4$ cubic feet per minute at 75 pounds pressure.

The ratio in column 2, Table XXVI., is 6.10 for 75 pounds and $170.4 \times 6.10 = 1,039.4$ cubic feet of free air.

The following tables of free air delivery for various initial pressures, and for differential pressure losses for lengths of 500 feet for the actual diameter of pipes, were computed by Mr. William Cox for Mr. W. L. Saunders, and have been kindly loaned the author for this work.

TABLES OF COMPRESSED-AIR TRANSMISSION.

(Computed by William Cox.)

WITH A DISCHARGE OF EQUIVALENT FREE AIR IN CUBIC FEET PER MINUTE FROM PIPES OF VARIOUS DIAMETERS FROM 1 TO 10 INCHES, EACH 500 FEET LONG, WITH VARIOUS REDUCTIONS OF THE FINAL PRESSURE.

From these tables, approximate quantities and loss of pressure may be obtained for any required length of pipe line.

FOR EXAMPLE.—It is required to deliver 2,000 cubic feet of equivalent free air at the end of a pipe line 150 feet long, the initial pressure being 60 pounds, and the loss of pressure not to exceed 10 pounds. What diameter of pipe must be used?

TABLE XXVII.—AIR TRANSMISSION. INITIAL GAUGE PRESSURE, 45 POUNDS.

Diameter of pipe.	REDUCTION OF FINAL PRESSURE IN 500 FEET.						
	1 pound.	2 pounds.	3 pounds.	5 pounds.	7 pounds.	9 pounds.	12 pounds.
1 inch.....	14	20	24	30	34	37	40
1¼ inches.	26	36	44	54	62	68	74
1½ “	43	60	72	90	102	112	121
2 “	95	132	159	198	226	247	268
2½ “	172	239	287	358	409	446	484
3 “	281	390	470	585	667	728	791
3½ “	419	583	701	874	997	1,080	1,180
4 “	595	827	995	1,240	1,410	1,540	1,670
4½ “	806	1,120	1,340	1,680	1,910	2,090	2,270
5 “	1,050	1,470	1,770	2,200	2,510	2,740	2,980
6 “	1,600	2,350	2,820	3,520	4,020	4,380	4,760
7 “	2,500	3,480	4,190	5,220	5,950	6,500	7,060
8 “	3,520	4,900	5,890	7,340	8,370	9,140	9,930
9 “	4,770	6,630	7,970	9,930	11,300	12,300	13,400
10 “	6,240	8,680	10,400	13,000	14,800	16,100	17,600

By table of 60 pounds initial pressure under 3 pounds loss, and opposite 5-inch diameter of pipe, we see that the delivery would be 2,000 cubic feet, so that for a pipe line 1,500 feet long the loss of pressure would be about $3 \times \frac{1,500}{500} = 9$ pounds. We say “about” 9 pounds, because the loss is not exactly proportional to the length, but nearly so when the basis of length is 500 feet.

TABLE XXVIII.—AIR TRANSMISSION. INITIAL GAUGE PRESSURE, 60 POUNDS.

Diameter of pipe.	REDUCTION OF FINAL PRESSURE IN 500 FEET.						
	1 pound.	2 pounds.	3 pounds.	5 pounds.	7 pounds.	9 pounds.	12 pounds.
1 inch. . . .	16	22	27	34	39	43	48
1 ¼ inches.	29	41	49	62	72	79	87
1 ½ " "	48	67	81	102	117	129	143
2 " "	107	149	180	226	259	286	315
2 ½ " "	193	269	325	408	469	516	569
3 " "	315	440	532	667	766	844	930
3 ½ " "	471	657	794	996	1,140	1,260	1,380
4 " "	668	932	1,120	1,410	1,620	1,780	1,970
4 ½ " "	905	1,260	1,520	1,910	2,190	2,420	2,660
5 " "	1,180	1,650	2,000	2,510	2,880	3,170	3,500
6 " "	1,890	2,650	3,200	4,010	4,610	5,080	5,590
7 " "	2,810	3,920	4,740	5,950	6,840	7,530	8,290
8 " "	3,960	5,520	6,670	8,370	9,620	10,500	11,600
9 " "	5,350	7,470	9,020	11,300	13,000	14,300	15,700
10 " "	7,010	9,710	11,800	14,800	17,000	18,700	20,700

TABLE XXIX.—AIR TRANSMISSION. INITIAL GAUGE PRESSURE, 75 POUNDS.

Diameter of pipe.	REDUCTION OF FINAL PRESSURE IN 500 FEET.						
	1 pound.	2 pounds.	3 pounds.	5 pounds.	7 pounds.	9 pounds.	12 pounds.
1 inch. . . .	18	25	30	38	44	48	54
1 ¼ inches.	32	45	55	69	80	89	98
1 ½ " "	53	74	90	113	131	145	161
2 " "	117	164	199	251	289	320	356
2 ½ " "	212	296	359	453	523	579	643
3 " "	346	484	587	740	855	946	1,050
3 ½ " "	517	723	876	1,100	1,270	1,410	1,560
4 " "	734	1,020	1,240	1,560	1,810	2,000	2,220
4 ½ " "	994	1,390	1,680	2,120	2,450	2,710	3,010
5 " "	1,300	1,820	2,210	2,780	3,220	3,560	3,950
6 " "	2,080	2,910	3,530	4,450	5,140	5,690	6,320
7 " "	3,090	4,320	5,230	6,600	7,630	8,440	9,370
8 " "	4,350	6,070	7,360	9,290	10,700	11,800	13,100
9 " "	5,880	8,220	9,960	12,500	14,500	16,000	17,800
10 " "	7,710	10,700	13,000	16,400	19,000	21,000	23,300

Professor Unwin has estimated that 10,000 horse power can be transmitted at an initial pressure of 132 pounds a distance of 20 miles in a 30-inch main with a loss of pressure of only 12 per cent; and that the motor efficiency at this distance may vary with cold air from 40 to 50 per cent and by reheating to 300° F. from 59 to 73 per cent. The air velocity for these estimates is based on 20 feet per second for best effect. The larger mains indicate a large saving in power for compression or for motor use, and indicate financial economy in the long run, especially

where future possibilities may require additional air power. One of the great mistakes heretofore made in piping mining and other air systems has been due to a false estimate of future wants or a mistaken judgment of the loss in air friction.

TABLE XXX.—AIR TRANSMISSION. INITIAL GAUGE PRESSURE, 90 POUNDS.

Diameter of pipe.	REDUCTION OF FINAL PRESSURE IN 500 FEET.						
	1 pound.	2 pounds.	3 pounds.	5 pounds.	7 pounds.	9 pounds.	12 pounds.
1 inch. . . .	19	27	33	41	48	53	65
1¼ inches.	35	49	59	75	87	97	109
1½ " "	57	80	97	123	143	159	178
2 " "	127	178	215	273	316	351	394
2½ " "	229	321	390	493	572	635	712
3 " "	375	525	636	806	934	1,030	1,160
3½ " "	560	784	950	1,200	1,390	1,550	1,730
4 " "	794	1,110	1,340	1,700	1,980	2,190	2,460
4½ " "	1,070	1,500	1,820	2,310	2,680	2,970	3,330
5 " "	1,410	1,970	2,390	3,030	3,510	3,900	4,370
6 " "	2,250	3,160	3,830	4,850	5,620	6,240	6,990
7 " "	3,340	4,680	5,680	7,190	8,340	9,260	10,300
8 " "	4,700	6,590	7,990	10,100	11,700	13,000	14,500
9 " "	6,360	8,930	10,800	13,600	15,800	17,600	19,700
10 " "	8,340	11,600	14,100	17,900	20,700	23,000	25,800

TABLE XXXI.—AIR TRANSMISSION. INITIAL GAUGE PRESSURE, 105 POUNDS.

Diameter of pipe.	REDUCTION OF FINAL PRESSURE IN 500 FEET.						
	1 pound.	2 pounds.	3 pounds.	5 pounds.	7 pounds.	9 pounds.	12 pounds.
1 inch. . . .	20	29	37	44	52	58	65
1¼ inches.	37	52	68	81	94	105	118
1½ " "	61	86	111	133	155	172	194
2 " "	129	190	245	294	341	380	427
2½ " "	245	344	443	531	617	687	772
3 " "	401	562	724	867	1,000	1,120	1,260
3½ " "	599	839	1,080	1,290	1,500	1,670	1,880
4 " "	850	1,190	1,530	1,830	2,130	2,370	2,670
4½ " "	1,150	1,610	2,070	2,480	2,890	3,220	3,610
5 " "	1,510	2,110	2,720	3,260	3,790	4,220	4,750
6 " "	2,410	3,380	4,350	5,220	6,070	6,760	7,590
7 " "	3,580	5,010	6,460	7,740	8,990	10,000	11,200
8 " "	5,030	7,050	9,080	10,800	12,600	14,000	15,800
9 " "	6,810	9,540	12,200	14,700	17,100	19,000	21,400
10 " "	8,920	12,500	16,100	19,200	22,400	24,900	28,000

Air losses in transmission in pounds per square inch for definite volumes through assigned pipe sizes, at the most-used pressure in mining and mechanical operations, viz., 80 pounds pressure, are given in Table XXXII.:

TABLE XXXII.—LOSS OF PRESSURE THROUGH FRICTION OF AIR IN PIPES, IN POUNDS PER SQUARE INCH FOR EVERY 100 FEET LENGTH OF PIPE (INITIAL GAUGE PRESSURE 80 POUNDS AT RECEIVER).

Equivalent volume of free air discharge per minute.	SIZE OF PIPE.													
	1".	1¼".	1½".	2".	2½".	3".	4".	5".	6".	7".	8".	10".	12".	14".
25	.24	.12												
50	1.00	.45	.18											
75	2.4	1.0	.4											
100		1.7	.70	.13										
200			3.00	.50	.175									
300				1.20	.38	.15								
400				2.15	.67	.27	.06							
500				3.30	1.10	.40	.10	.03	.012					
750					2.50	.91	.22	.07	.03	.013				
1,000						1.8	.40	.12	.05	.023	.012			
1,500						4.00	1.00	.30	.12	.052	.027			
2,000							1.60	.50	.20	.095	.048	.017		
3,000							3.70	1.20	.45	.22	.115	.036	.015	
4,000								2.00	.80	.39	.20	.07	.026	.012
5,000									1.30	.60	.30	.10	.041	.018
6,000									1.9	.85	.43	.15	.06	.028
7,500									3.00	1.40	.68	.22	.09	.04
10,000										2.5	1.25	.40	.17	.075

EXAMPLE.—An air compressor furnishes 500 cubic feet of free air per minute at a pressure of 80 pounds per square inch in the receiver. If this air is used at the end of a 3-inch pipe 1,000 feet long, the loss due to friction will be $10 \times .4 = 4$ pounds. If the same volume of air were supplied by the same compressor at the same pressure and passed through a 5-inch pipe, 1,000 feet long, the loss would be only $.03 \times 10 = 3 - 10$ pounds; thus illustrating the importance of using pipe of large diameter. Strictly speaking, the loss of pressure is not directly proportional to the length; however, for all practical purposes it may be taken as such.

The foregoing table represents the loss by friction in the pipe. There is a further slight loss due to the friction of the air with itself at the mouth of the pipe as it leaves the receiver.

All leaks in compressors or valves, air receivers, or pipe, should be strictly guarded against for the sake of economy in the running of compressed air and steam apparatus. Air leaks are fully as expensive as steam leaks, and should be as carefully stopped. Too many operators think that an air leak is of but little consequence, but it should never be allowed, save where needed for actual ventilation.

Chapter XV.

COMPRESSED-AIR REHEATING AND ITS WORK

COMPRESSED-AIR REHEATING AND ITS WORK.

ONE of the most important economies in the use of compressed air is the saving obtained by the increased volume due to reheating. The first efforts made in this line were probably suggested by the tendency of rock drills to become so frosted in the exhaust as to interfere with their best work.

Experiments made by placing a wad of oily waste in a chambered fitting, close to the steam chest of a drill, which was found to burn freely fed by the passing air, led to trial of a miner's lamp in a small chamber, by which arrangement the products of combustion were added to the compressed air and, passing through the cylinder, modified in a great measure the intensity of the frosty exhaust.

In Fig. 61 this simple reheater is illustrated in its primitive form. The experiment clearly demonstrated the possibility of utilizing the heat and products of combustion for their full value.

Another experiment in the same line is shown in Fig. 62, in which any easily combustible fuel can be enclosed in a chamber above a wire-gauze partition in an enlarged fitting close to the air chest. An opening in the fitting, not shown in the cut, allows of igniting the combustible in contact with the wire gauze, when the combustion is kept up by the passing air and is fed by gravity from above. This method of reheating intensifies combustion and is fairly safe in mine drilling and pumping.

Another form of internal combustion reheater, patented by "Edison," is illustrated in Fig. 63, and consists of a chamber

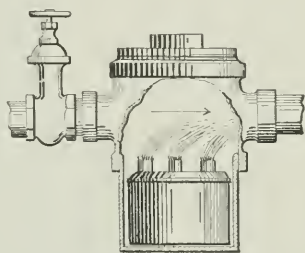


FIG. 61.—SIMPLE REHEATER.

within a chamber, between which the air flows and is heated by a fire within the internal chamber. A by-pass regulated by

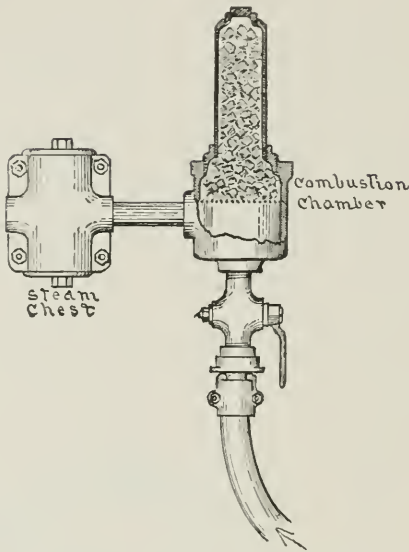


FIG. 62.—ROCK-DRILL REHEATER.

a valve allows enough air to pass under the grate to feed the fire. A jacketed pipe leads the products of combustion from the top of the fire-chamber to the following main air pipe, also regulated by a valve. A closure in the main intake air pipe produces a differential pressure which insures circulation through the fire-chamber. A hand-hole plate at the top fastened by a yoke and screw allows of access for feeding fuel, and a full-sized head and yoke at the bot-

tom allow of thorough cleaning. In ordinary operation the fire can be fed and ashes blown out without interrupting the main flow of air, by operating the by-pass valves.

Reheaters of the class used in the Popp compressed-air system in Paris are made with pipe coils in a stove for small motors, and with cast-iron double-chambered stoves in which the products of combustion are carried to a chimney and wasted. The Sergeant reheater (Fig. 64) is a double-chambered stove in which all the compressed air passes vertically through the space between the fire-box and the outer shell. The fire is fed from the top, and can be stoked through the open grate at the bottom.

This form of reheater is in general use, and is as simple and easily managed

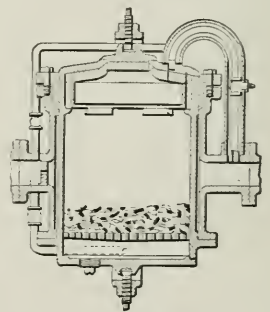


FIG. 63.—EDISON REHEATER.

as is possible under most of the conditions available for economizing the use of compressed air in motor engines.

From tests made with this heater it has been found capable of heating 340 cubic feet of free air per minute at 40 pounds pressure to 360° F., giving a gain of 35 per cent in the meas-



FIG. 64.—THE SERGEANT REHEATER.

ured amount of work done by the air after passing through the heater, compared with the same volume of air when used cold.

A heater of this size will heat less air to a higher temperature or more air to a lower temperature, than stated above; but if it should be required to heat more than 400 cubic feet of free air per minute, to get the best economy it is advisable to use the heaters in series, allowing about 400 cubic feet of free air per minute for each heater. The heater should be placed

as near as possible to the point where the air is to be used, and the outlet pipe should be as short as possible and well covered, so that the air will retain its heat.

Trials have been made in reheating compressed air by injecting steam into the air pipe near the motor, by passing the air through a steam boiler, and in the Mekarski and other compressed-air systems by passing the air through a tank charged with water at a high temperature.

Experiments have been made with a combination of steam with compressed air with an economy of 25 per cent in air volume by an expenditure of $1\frac{1}{2}$ pounds of coal per horse-power



FIG. 65.—THE "SERGEANT."

Reheating the air for rock-drilling and pumping in Jerome Park Reservoir.

hour for the steam used, and was found to be equivalent to an additional horse power for each pound of coal burnt in the heater.

In consideration of the unavailability of steam except in a few locations where steam at high pressure is in use near the location of compressed-air engines, the heating of compressed air by steam for motors is of little or no practical value. Reheating by the hot-water system as used on railway cars has proved very economical.

The reheater of the Rand Drill Company, New York City, is illustrated in Figs. 66 and 67, and has a furnace lined with fire-brick and an ordinary fire and ash-pit door. The heating surfaces are composed of concentric annular spaces of gradually

increasing area, keeping the velocity of the expanding air constant. The air enters at the side of an annular chamber shown in Fig. 67, passing around the heater and upward and down-

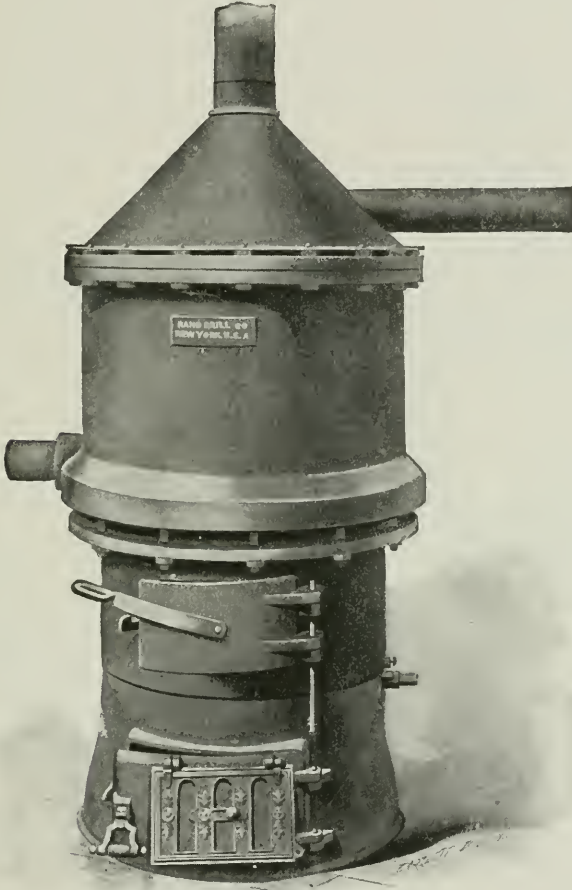


FIG. 66.—THE RAND REHEATER.

ward and then upward through the thin annular spaces, making its exit at the top of the interior and hottest space.

In a test with a reheater of this type having $8\frac{1}{2}$ square feet of heating surface, 530 cubic feet of free air under 60 pounds pressure were heated from 84° to 376° F. in one minute; with exhaust air from the motor, as a forced draft, the temperature

was raised to 450° F. for the same quantity of air; 300° is the most practicable temperature to operate motors and drills on account of oil lubrication; but the air temperature at the reheater may be higher to compensate for the distance of transmission.

The use of superheated water forced into tanks for car motor service has become an established system, showing the best

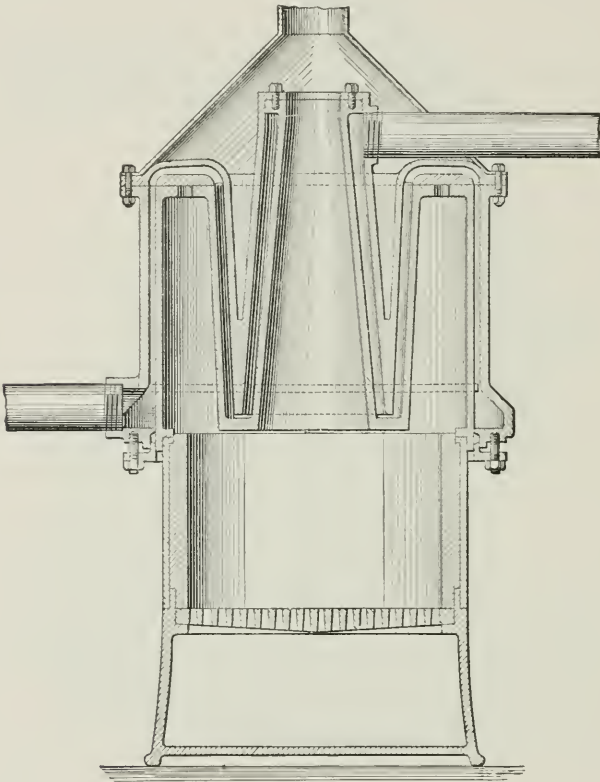


FIG. 67.

economy for this class of service, and seems to be the only available means that does not require the management of a fire on the motor car.

The hot-water reheater of the Mekarski system as used on a number of compressed railways in England, France, and Switzerland is illustrated in Fig. 68. The reheater is charged at the station with water at about 100 pounds or more pressure

at a temperature at or above 338° F., containing nearly 1,200 heat units per pound of water. In the early water reheaters of this class the air was injected from a nozzle in the bottom of the heater as shown in the cut, and thereby absorbing water vapor to saturation with but little excess of steam. In Fig. 69 is illustrated the details of this reheater as used on the Nantes, France, compressed-air tramway, in which the compressed air enters the heater at the side near the bottom, and is divided into small streams issuing from a perforated pipe and, bubbling up through the water, becomes heated to the temperature of the water, and also takes a considerable excess of hot vapor or steam, depending upon the relative pressures of the air and the

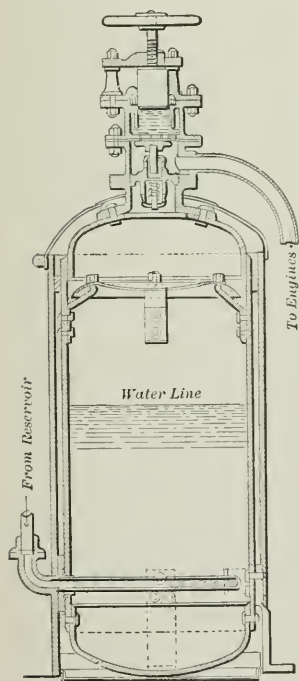


FIG. 69.—MEKARSKI REHEATER.

pressure due to the temperature of the water.

A diaphragm above the water line serves to prevent particles of water from escaping through the reducing valve when thrown up by the agitation of the passing air. The reducing or regulating valve is of a peculiar construction as shown in the cut. The hand-wheel when turned lowers or raises a plunger; this acts upon a liquid contained between it and a diaphragm resting upon the head of a spring valve closing against the reservoir pressure.

Just around the plunger there is an annular air space acting as an air vessel. When the plunger is depressed

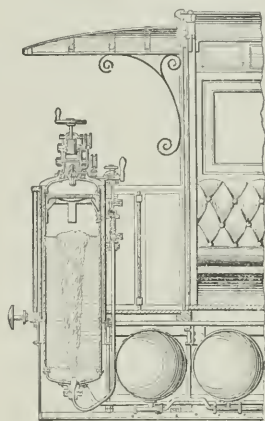


FIG. 68.—MEKARSKI REHEATER.

into the liquid, the result is to compress the air in the air vessel to any desired extent. Then, on the air cock being opened, air bubbles through the hot water, and rises past the cone valve, which is attached to the diaphragm into the space below it, so as to press on the under-side of the diaphragm and tend to raise it; but it cannot do so until the pressure of the air below the diaphragm equals that in the annular air vessel above, and thus the pressure in the annular air vessel is automatically the measure of the pressure that will prevail in the engines. So soon as this is exceeded the diaphragm rises and closes the valve; and so soon as it falls the air in the annular air vessel re-expands and lets in more compressed air. In this way the driver can, from time to time, vary the pressure by his hand-wheel, confident that, whether the engines are running quickly or slowly, the pressure will be steadily maintained. The automatic regulating valve and the employment of the "hot-water chamber" are the distinguishing features in this particular system—the Mekarski system—of using compressed air.

The economic value of reheating compressed air in close proximity to an air motor or engine by a surface heater of the Sergeant, Rand, or Edison type is fully shown in column 2 of Table XV., which gives the increase in volume from any initial temperature to any other temperature at which the air emerges from the heater.

In a surface heater of good form the loss of fuel heat from radiation and by the smoke-pipe should be no greater than 50 per cent of the total heat value of the fuel, or, say for coal, a useful effect of 7,000 heat units per pound. This should heat $\frac{7,000}{.2375} = 29,463$ pounds of air 1° F. If to be heated from 60° to 360° , at which temperature the volume would be increased, as found in column 2, Table XV., from 13 cubic feet to 20.63 cubic feet per pound; or $\frac{13}{20.63} = 63$ per cent by reheating to an amount of 300° . Then $\frac{29,463}{300} = 94.8$ pounds heated from 60°

to 360° , and $94.8 \times 13 = 1,232.4$ cubic feet of initial free air, heated from 60° to 360° by 1 pound of coal. The increase in volume equals $1,232 \times .63$ per cent, or 776 cubic feet. Then if 10 cubic feet per minute represents 1 horse power in an air motor at any specified pressure, there should be a production of 77 horse power by reheating air to an amount of 300° by the burning of 1 pound of coal per minute, or 1.28 of a horse power per 1 pound of coal per hour, a far better result than can be anticipated from any known condition of steam power.

When the entire products of combustion are utilized there is no loss save radiation, and we can safely count on 90 per

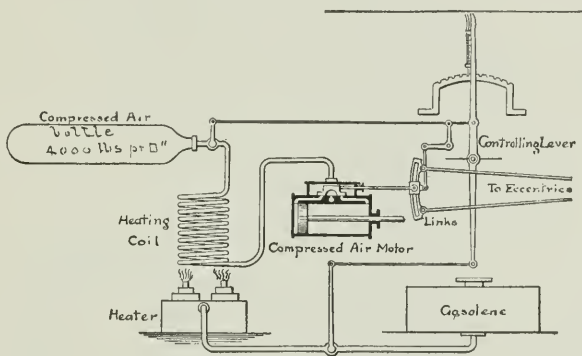


FIG. 70.—AUTOMOBILE REHEATER.

cent of the total heat units for effective work in reheating compressed air for power. Thus by the internal combustion system the saving of 2.4 horse power per pound of coal per hour may be accomplished.

The method of reheating compressed air for automobile motors is shown in Fig. 70. The air stored at high pressure issues through a copper coil at reduced pressure controlled by link-valve gear, and reheated in its passage to the motor by gasoline or kerosene burners.

Small storage-bottles of steel are made to hold 260 times their volume, or about 4,000 pounds pressure per square inch.

THE CALORIC OR HOT-AIR ENGINE.

The expansion and contraction of air by the absorption and elimination of its element of heat give to air a power for work which has been utilized to a small extent for motive power during the past century. The open-cycle system of its application in the early motor engines did not prove satisfactory or efficient.

The most satisfactory and efficient system has been derived from Carnot's suggestion of the closed cycle of heat transfer in which the pressure element of air is kept within the motor, while the heat element is generated from the outside, transmitted through the enclosed air for work, and eliminated at the cold end of the cycle by a cooling medium; and then the air is returned to the heat-imparting chamber by the alternating of two pistons.

This is the type of the action of the Ericsson pumping engine with tandem pistons in a single cylinder, and the Rider two-cylinder hot-air engine. Other hot-air engines are of the Roper type in which the heat products of combustion from an internal furnace are absorbed in or mixed with the air in its open-cycle progress through the motor, the furnace being fed with air from a pump driven by the motor. The hot air and gases are exhausted from the cylinder at the close of each power stroke.

Some trouble has been found in this class of hot-air motors from the ashes lodging in the working parts, and so clogging and wearing the surfaces.

The rapid wear of working surfaces of valves and cylinder, and the difficulties in properly lubricating caused by the intense heat and ashes, have retarded their general use, apart from their bulky proportions.

The Stirling hot-air engine, used in England and on the continent from 1816 and further improved about 1827, operated

on the closed-cycle system with a regenerator, using the air at constant initial volume with pressures due to change of temperature and intensified by the capacity of the regenerator for

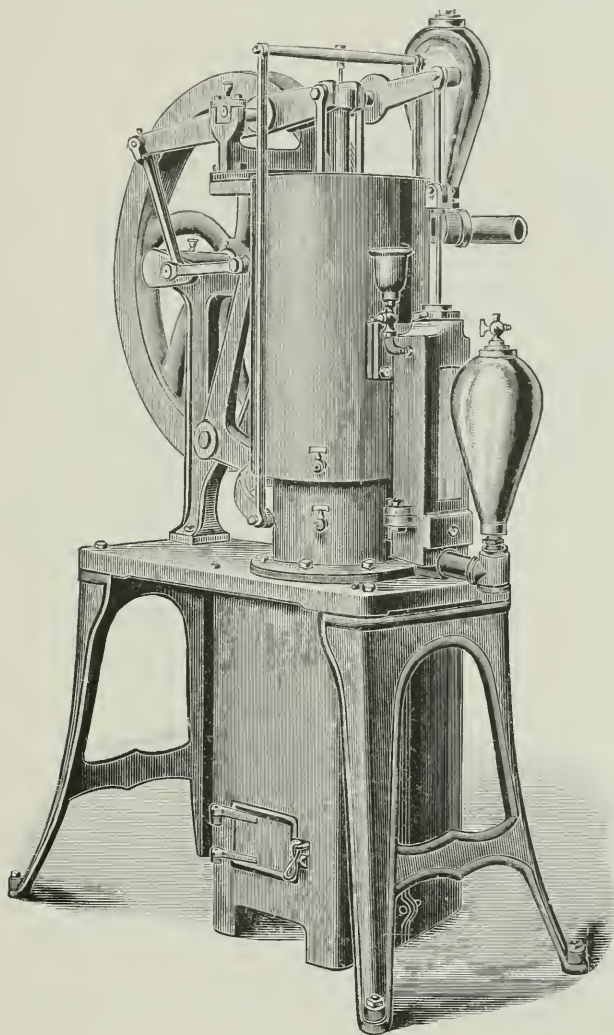


FIG. 71.—THE FRICSSON PUMPING ENGINE WITH COAL-FIRE FURNACE.

the absorption and elimination of heat from and to the air as it passed between the heating and cooling surfaces in the cycle. This engine required two cylinders, one of which was the power and cooling cylinder, and the other was the heating cyl-

inder containing the transfer piston. The modern Rider hot-air engine is an improved type of the Stirling engine.

The Ericsson modern type of pumping engine, as made by the Rider-Ericsson Engine Company, New York City, has the power piston and transfer piston working tandem in the same

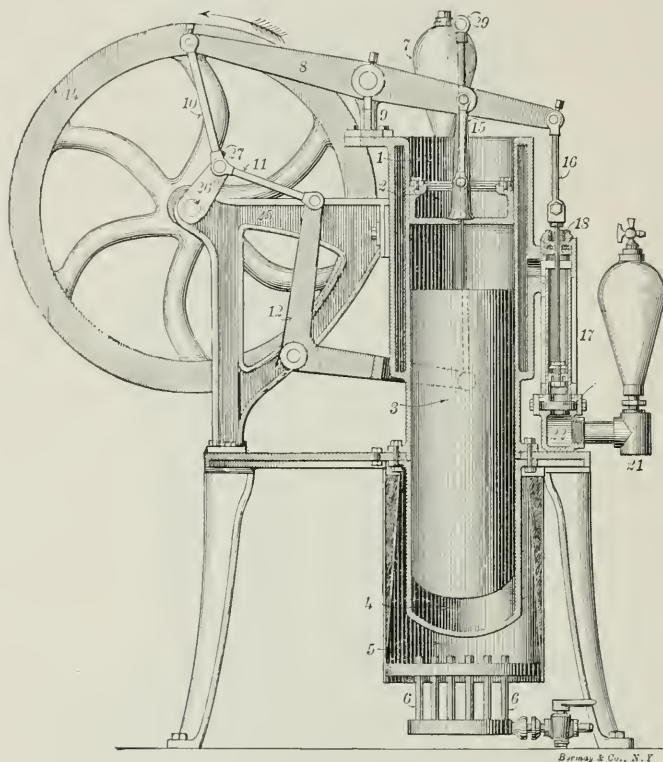


FIG. 72.—SECTION OF ERICSSON PUMPING ENGINE, WITH BUNSEN-BURNER GAS FURNACE.

1, Cylinder; 2, air piston; 3, transfer piston; 4, heater; 5, furnace; 6, gas burners; 7, air chamber; 8, main beam; 9, beam centre bearing; 10, connecting rod; 11, bell-crank link; 12, bell crank; 14, fly-wheel; 15, air piston links; 16, pump link; 17, pump chamber; 18, pump gland; 19, suction valve; 21, suction pipe; 22, pump bottom; 25, crank-shaft bracket; 26, crank; 27, crank pin; 29, transfer piston-rod, cross-head.

cylinder, as represented in Figs. 71 and 72. It operates without a special regenerator. The hot air from the heating chamber passes in a thin stratum along the outside of the transfer piston, and is cooled in its course toward the working piston by convection from the water-jacketed surface of the upper part of

the cylinder, the pumped water passing through the cylinder jacket for this purpose.

In the type of the Rider hot-air engine, operating through the same recurring cycle and at a constant initial volume with differential heat pressures, the extremes of heat and cold are established in different cylinders, the pistons being operated from a common shaft with cranks at right angles to meet the cyclic requirement, as shown in the cut (Fig. 73). The office of the regenerator is to intensify the extreme temperatures by absorbing much of the heat of the air as it passes from the heat cylinder to the cold cylinder, and to return the same heat to the air in its return from the cold to the hot cylinder. This operation gives a greater range to the temperature, and thereby increases the range of pressures.

Actual observation of the temperature at each end of the regenerator has shown a difference of 300° F., which indicates a considerable differential pressure, modified by the proportional part of the air volume in the two cylinders not acted upon by the regenerator. This may equal a mean differential temperature of 250° F. for the whole volume of the enclosed air. The respective volumes will then become as 1 to 1.27, and the pressures 0 to 4.23 pounds per square inch during a half revolution, with probably a mean pressure of $2\frac{1}{2}$ pounds per square inch during a revolution of the fly-wheel. This will be equivalent to about 2,500 foot-pounds, minute, in a 5-inch engine, or nearly one-twelfth of a horse power.

The indicator card (Fig. 74), taken from a Rider two-cylinder hot-air engine by Professor Hutton, represents the cycle of pressures derived from the apparently erratic motion of cranks at right angles and operated by two pistons, both of which were under variable pressure from heat expansion in a constant initial volume of air.

The drop of the indicator line below the atmospheric line during a half-stroke indicates a leakage of air under the pressure of three half-strokes, or three-quarters of a revolution.

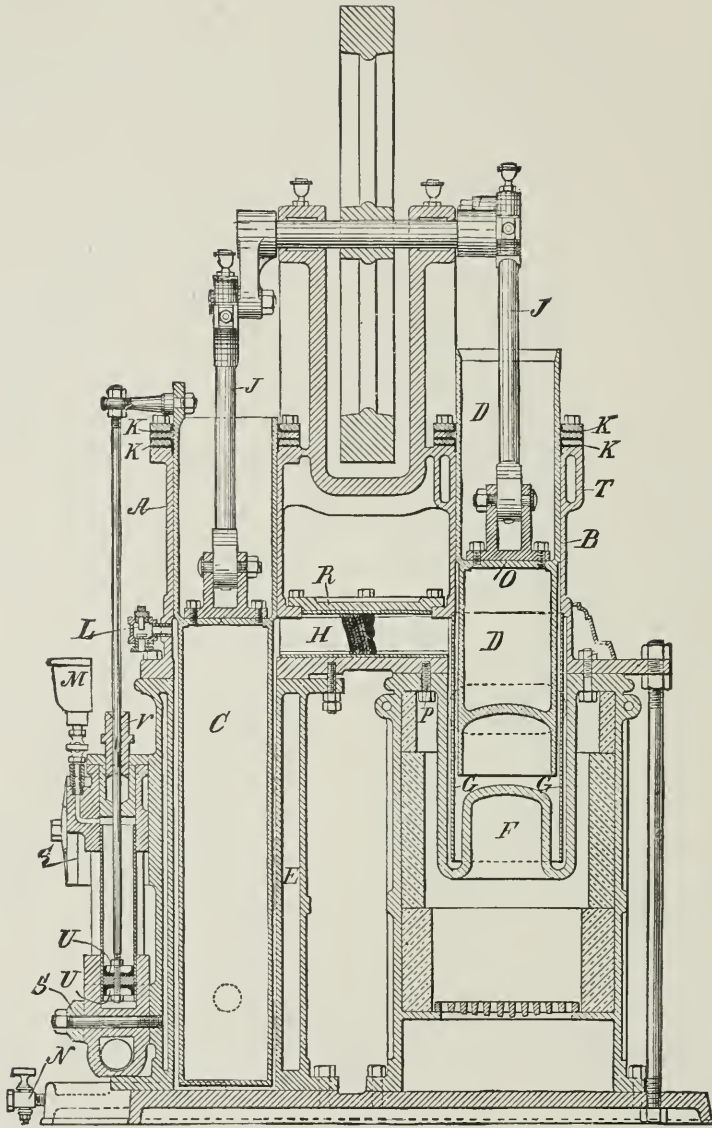


FIG. 73.—SECTION OF THE RIDER HOT-AIR PUMPING ENGINE.

A, Compression cylinder; *B*, power cylinder; *C*, compression piston; *D*, power piston; *E*, cooler; *F*, heater; *G*, telescope; *H*, regenerator; *I I*, cranks; *J J*, connecting rods; *K K*, piston packings; *L*, check valve, at back of compression cylinder; *M*, pump primer; *N*, blow-off cock; *R*, regenerator bonnet; *S S*, pump-valve bonnet; *T*, water jacket, to protect packing from heat; *U U*, pump buckets; *V*, pump gland.

The hot-air engines of the Ericsson-Rider type do not operate on the constant-volume cycle; for the operation of the working pistons varies the relative volumes by the differential length of the cranks and consequent amount of the volume of the stroke, and also does not operate at constant pressure; hence, the heat volume of the air is variable. At constant pressure a motor piston cannot pass through a cyclical movement and do work. So that it becomes evident that in the investigation of the movement of the pistons of this class of engines, the volume and pressure are both variable, and that

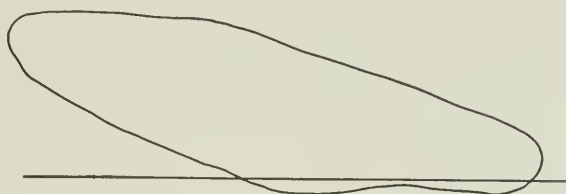


FIG. 74.—INDICATOR CARD.
Rider hot-air engine.

both volume and pressure are made variable by heat exchange and thus become the elements of motive power.

In the traverse of the two pistons in the Ericsson type the transfer piston is neutral in pressure, save the air friction; but in the Rider type the two pistons are of equal size, single acting, both working against the outer atmospheric pressure, and have the internal pressure equal on both pistons, save the air friction by transfer. Its power is derived from the differential stroke, the transfer piston having the longest stroke by about 16 per cent. The Ericsson hot-air pumping engine is made in four sizes, viz., 5-, 6- 8-, and 10-inch diameter of cylinder. The Rider hot-air pumping engine is made in five sizes, viz., 4-, 5-, 6-, 8-, and 10-inch diameter of cylinders.

Chapter XVI.

THE COMPRESSED-AIR MOTOR

THE COMPRESSED-AIR MOTOR.

THE published literature of recent date on the operation and efficiencies of compressed-air motors and the larger engines is too scant to quote their actual work at the present time; and especially when the engines of the present day are designed along the lines of the highest duty that can be given to the high-speed type and Corliss model. The operation of the latter is most desirable for obtaining the high efficiency that should be expected from the best designs and appliances for generating compressed air, and for its most useful work in our best-constructed engines with reheating appliances.

Our principal source of information in regard to the operation of compressed-air motors or engines is derived from the work of Professor Kennedy and others in their examinations and experiments at the compressed-air plant in Paris, France. From the class of compressors and motors in use at that time (1889) the results are not satisfactory; but it is hoped that the improvements in the efficiency of compressors and motors of the present day will enable us to show a considerable increase in the economy of the use of compressed air in compression, transmission, and for motive power, over these conditions as observed in the Paris plant. The small rotary engines in use in the Paris plant are convenient and compact, of high speed, and use the air with little or no expansion and without reheating, and of course have no pretence to economy in the use of air. The larger-sized motors and engines of the reciprocating type are of the ordinary slide-valve gear with automatic cut-off, controlled by a governor, and mostly provided with reheaters, which have been gradually improved until the later models seem to be very efficient in raising the temperature of the exhaust above the freezing-point.

Where refrigeration or cooling effect from the exhaust is desired, the reheater is modified or dispensed with. The value of reheating in the later forms of the Paris apparatus is to raise the temperature from 175° to 318° F. above the normal temperature, or to increase the volume of compressed air up to 60 per cent greater than its normal volume, at a cost of two-tenths of a pound of coal per horse-power hour. (See article on reheating.)

In Fig. 75 is a diagram or indicator card showing the conditions of air compression and motor work of this Paris plant as given by Professor Kennedy. It may be noticed in the dia-

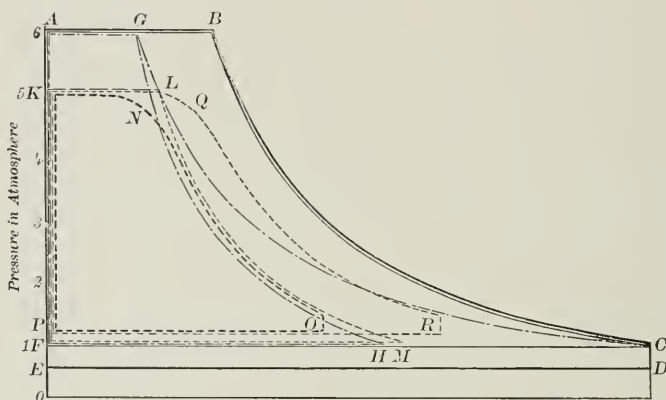


FIG. 75. COMPRESSOR AND MOTOR WORK.

gram that the compression was almost adiabatic as shown on the double line $B C$, showing want of jacket cooling, the upper line $B C$ being adiabatic; the closeness of these lines being attributed partly to resistance in the discharge valves, so that the work of the compressors was practically adiabatic. The area $A B C D E$ represents on any scale the work done in the steam cylinder, and the area $A B C F$ the work done by the same scale on the air in the compressors. $C G$ is the isothermal line of compression, so that $A G$ represents the volume of the compressed air when it has fallen in the mains to the initial temperature at C . $G H$ is the adiabatic curve of expansion from the volume at G ; the area $A G H F$ is 61 per cent of the area $A B C F$ (and 52 per cent of the area $A B C D E$). It rep-

resents the maximum work that can be obtained in a motor without reheating. Again, if the pressure falls from A to K by transmission, the volume increases from $A G$ to $K L$, the point L lying on the isothermal line $G C$. The loss of possible work due to such a reduction of pressure is represented by the differences between the areas $A G H F$ and $K L M F$, in both of which the expansion curves are adiabatic. The area $K N O P$ represents the actual work of the motor without reheating, and the area $K Q R P$ represents the actual work of the motor by reheating the air to 320° F.

In Fig. 76 is shown a sample card from a 10 horse-power English engine which was the subject of test in the Paris plant, and which represents the area $K N O P$ in the diagram (Fig. 75), and with 9.9 indicated horse power was using 14.8 cubic feet of free air per horse power per minute. The dotted lines are isothermal, and the contour of the card shows defects in the valves or their motion and irregular adjustment of cut-off.

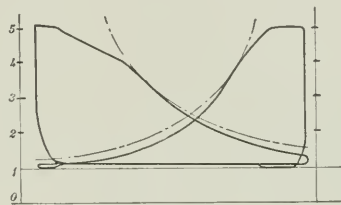


FIG. 76.—SLIDE VALVE CARD.

The theoretical power of the air used should have been 11.6 cubic feet of free air per horse-power minute, making the indicated efficiency of the motor .79; but from undue weight and friction of the motor the mechanical efficiency was but .67.

Late experiments with the rotary motors used in the Paris compressed-air system show a most extravagant use of free air per horse power, viz., 17.4 cubic feet per horse-power minute with cold air, and 13.9 cubic feet when the air was heated to 122° F., with an efficiency of 43 per cent.

Many of the motors now in use in Paris have an efficiency of only from 65 to 75 per cent, while a few of the best modern construction show a mechanical efficiency of 91 per cent. In one of the tests of late date, on an 80 horse-power engine that had been used as a steam engine, and for the purpose was supplied with an air reheater in which the temperature of the air

used was 320° F., the engine used but 7.54 cubic feet of free air per horse-power minute, corresponding to a total efficiency of 80 per cent. In this test the consumption of coke for reheating was 0.176 pounds per horse-power hour. The exhaust air temperature varied somewhat in difference with various initial temperatures not readily accounted for. When the initial temperature was 305° F. the exhaust was 84° , a difference of 221° . With 320° the exhaust was 95° , difference 225° , and with 338° the exhaust was 120° , difference 218° .

For comparison with present and future work of compression, transmission, and work of the motor, we give the following summary of the efficiencies of the Paris compressed-air plant as reported by Professor Kennedy, from which there has been but slight change, except perhaps in the later introduction of more economical motors and an increase in the reheating temperature:

One indicated horse power at central station gives 0.845 indicated horse power in compressors, and corresponds to the compression of 348 cubic feet of air per hour from atmospheric pressure to 6 atmospheres absolute.

Efficiency of main engines, 0.845.

0.845 indicated horse power in compressors delivers as much air as will do 0.52 indicated horse power in adiabatic expansion after it has fallen in temperature to the normal temperature of the mains.

$$\text{Efficiency of compressors } \frac{0.52}{0.845} = 0.61.$$

The fall of pressure in mains between central station and Paris (say 5 kilometers) reduces the possibility of work from 0.52 to 0.51 indicated horse power.

$$\text{Efficiency of transmission through mains } \frac{0.51}{0.52} = 0.98.$$

The further fall of pressure through the reducing valve to $4\frac{1}{2}$ atmospheres ($5\frac{1}{2}$ atmospheres absolute) reduces the possibility of work from 0.51 to 0.50.

$$\text{Efficiency of reducing valve } \frac{0.50}{0.51} = 0.98.$$

The combined efficiency of the mains and reducing valve, between 5 and $4\frac{1}{2}$ atmospheres, is thus $0.98 \times 0.98 = 0.96$. If the reduction had been to 4, $3\frac{1}{2}$, or 3 atmospheres, the corresponding efficiencies would have been 0.93, 0.89, and 0.85 respectively.

Incomplete expansion, wire-drawing, and other such causes reduce the actual indicated horse power of the motor from 0.50 to 0.39.

$$\text{Indicated efficiency of motor } \frac{0.39}{0.50} = 0.78.$$

Indicated efficiency of whole process with cold air, 0.39.

By heating the air before it enters the motor to about 320° F., the actual indicated horse power at the motor is increased, however, to 0.54. The ratio of gain by heating the air is, therefore, $\frac{0.54}{0.39} = 1.38$.

Apparent indicated efficiency of whole process with heated air, 0.54.

In this process additional heat is supplied by the combustion of about 0.39 pound coke per indicated horse power per hour, and if this be taken into account the real indicated efficiency of the whole process becomes 0.47 instead of 0.54.

Real indicated efficiency of whole process with heated air, 0.47.

Working with cold air the work spent in driving the motor itself reduces the available horse power from 0.39 to 0.26.

Mechanical efficiency of motor, cold, 0.67.

Working with heated air the work spent in driving the motor itself reduces the available horse power from 0.54 to 0.44.

Mechanical efficiency of motor, hot, 0.81.

Since the first instalment of the Paris plant a marked improvement has been made in the design of the compressors of a new plant, in which two-stage compression and intercooling has been introduced, in which an efficiency of 98 per cent is claimed as between the indicated power of the engine and compressor.

A HYDRAULIC AIR-COMPRESSING PLANT.

The following abstract of a report furnishes some interesting details of the air plant of the North Star Mining Company, Grass Valley, Cal., and what has been and can be done through the medium of impact wheels under high water pressure:

"For this plant the water supply is obtained from the South Yuba Water Company at a point on their canal about four miles from Grass Valley, Nevada County, Cal. Thence it is conveyed about two and one-half miles to the Empire Mining Company's works in a 22-inch riveted iron pipe, built more than ten years ago. The new conduit is a riveted steel pipe, 20 inches in diameter, joined to the lower end of this old one under a head of 420 feet, and continues 7,070 feet to the power-house, situated at the lowest convenient point on Wolf Creek, just below the town of Grass Valley, where a head of 775 feet, or a static pressure of 335 pounds per square inch, is obtained. The capacity of this pipe is sufficient to develop 800 to 1,000 horse power.

"At the power-house there is a Pelton water-wheel, 18 feet 6 inches in diameter, running on a 10-inch shaft, to which a duplex compound air compressor is connected directly. The initial cylinders are 18 inches, and the second cylinders are 10 inches in diameter with a 24-inch stroke. They were designed to run at 110 revolutions per minute, and require 283 horse power from the water-wheel.

"A 6-inch lap-welded pipe conveys the air at 90 pounds pressure from the power-house to the company's Stockbridge shaft on Massachusetts Hill, 800 feet distant and 125 feet higher. Here it is being used in a 100 horse-power cross-compound Corliss pneumatic hoisting engine, and a 75 horse-power compound pump, beside other pumps, blacksmith forge, drills, etc.

"About 1,000 feet from the lower end a 12-inch branch with a gate is put in for possible future use, and near it is a 20-inch

gate. At the lower end of the pipe in the power-house there is another 20-inch gate, below which is a 12-inch branch leading to the Pelton wheel, and adjoining this is the receiver, 2 feet in diameter, on which are the air chambers, charging tube, and relief valve. The air chamber is a 10-inch lap-welded tube 18 feet long standing on the receiver, with an 8-inch gate between. The charging tube is similar, but 8 inches in diameter. Both have 2-inch water discharge pipes and gates, and by proper manipulation of the gates and the operation of inlet check valves on top of the tubes, the air chamber may be filled. Ordinarily the charging-tube is filled up to 90 pounds pressure from the air compressor delivery pipe, and then raised by the water pressure. It is found necessary to put in about one-tenth of the volume of the air chamber every day. Where the air goes is, thus far, a mystery, as no leak has been discovered." This should be no mystery, for it is well known that water under great pressure absorbs a large addition to its natural holding under atmospheric pressure. "The demand for direct action under a head of 775 feet made a large wheel necessary in order to obtain the proper peripheral speed of half the spouting velocity. This could not readily be done, and a wheel of $18\frac{1}{2}$ feet diameter was made by the Pelton Company of San Francisco, who guaranteed an efficiency of 85 per cent of the water value at full load, and an average of 75 per cent from half to full load of the theoretical power of the water, and, at the same time, to so govern the wheel that it should not exceed 120 revolutions nor raise the air pressure above 105 pounds per square inch in case of accident to machinery or sudden shutting-off of air. The rim is built up of angles and plates riveted together to break joints. It weighs about 6,800 pounds, and is held concentric with the shaft by twelve pairs of radial spokes of $1\frac{1}{4}$ -inch rod iron held by nuts to the cast-iron hub. The driving force, being applied to the rim, is transferred to the hub by four pairs of 2-inch iron rods, so arranged as to form a truss. The wheel is set on a 10-inch shaft, having a disc crank on

either end and connected directly to the compressors. The regulator is a floating valve actuated against excessive velocity by the ordinary ball governor and against excessive air pressure by a spring set to move when the air pressure in the delivery pipe exceeds 90 pounds.

"Repeated tests which checked very closely give the wheel an efficiency of a trifle over 90 per cent for one-quarter, one-half, three-quarters, and full loads. Between these points it is somewhat less, as the hood coming down over the nozzle tends to deflect the water as well as hold it back, and decreases the efficiency. It seems probable that the long radius of the wheel accounts for the high efficiency.

"The compressors were built by the Fulton Engineering and Ship-Building Company of San Francisco. They are made very heavy, to stand the high piston speed required by the conditions of the water power. The compressor cylinders are 18 and 10 inches in diameter and 24 inches stroke.

"The most novel feature of these machines is the intercooler. This is made up of forty-nine soft copper pipes, 1 inch in diameter, 18 feet long, each with a stuffing-box at each end connected with manifold castings. The air delivered from the first cylinder into one manifold passes through these pipes to the other manifold, from which it is taken to the second cylinder. The whole is placed in the wheel pit directly under and in front of the wheel, so that the water dashes all over and through it. The air, leaving the first cylinder at a temperature of 200° F., passes through the intercooler and enters the second cylinder at 60°, slightly cooler than when entering the first cylinder. The temperature is again raised to 204° on leaving the second cylinder and passing into the transmission pipe, showing a total rise in temperature of 282° F. from both stages.

"The transmission pipe, conducting the air at 90 to 100 pounds pressure about 800 feet from the compressors to works at the mine, is ordinarily well tubing 5¾ inches in diameter inside. At the mine there is the ordinary air receiver and

also three 50-horse-power boilers set ready for steam, which are used for receivers.

"The air is taken from these into the reheaters. It requires a little over half a cord of good pine wood each twenty-four hours to heat about 700 cubic feet of free air per minute to a temperature 350° to 400° F. The heated air passes through pipes covered with magnesia and hair-felt to the first cylinder of the hoisting engine, from which it is exhausted back into the upper heater, where its temperature is again brought to 350° , whence it passes to the second cylinder at 30 pounds pressure. From this it is exhausted through a flue to the change house, where it is used for heating and drying clothes. From the first heater also the air for the pump is conveyed some 300 feet down the shaft in a similarly covered pipe. It receives the air at about 275° and exhausts it into the shaft at about 60° , thus giving plenty of pure cool air to the men, without the usual fans or ventilators.

"A direct-acting donkey pump is situated in another shaft 750 feet distant, to which air is carried cold in a 2-inch pipe over the surface. An old hot-water heater is used as a reheater for the air, and consumes twelve sticks of pine cord-wood per twenty-four hours.

"The hoisting engine is a compound direct-acting Corliss of 100 horse power with cylinders jacketed for hot air, and is calculated to work 3,000 feet down an incline of about 35° .

"There is 304 theoretical horse power in the water used at the power-house, the work actually accomplished at the mine amounts to 203 horse power, and the cost of reheating is \$3 per day.

"Efficiency of compression and transmission from water wheel to motors, and not including cost of reheating	$\frac{225.32}{283} = 79.5$ per cent.
Efficiency of compression and transmission from theoretical power of the water to the motors, and not including cost of reheating	$\frac{225.32}{304} = 74$ per cent.
Efficiency from the water-wheel to and through the motors, not including reheating	$\frac{202.7}{283} = 71.6$ per cent.

Efficiency from the theoretical power of the water, to and through the motors, and not including the cost of reheating.....	$\frac{202.7}{304} = 66$ per cent.
Efficiency of compression and transmission from water-wheel to motors, including the cost of reheating expressed in water power.....	$\frac{225.32}{307.66} = 73$ per cent.
Efficiency of compression and transmission from the theoretical power of the water to the motors, including the cost of reheating expressed in water power	$\frac{225.32}{329} = 68.4$ per cent.
Efficiency of compression and transmission from the water-wheel to and through motors, including cost of reheating expressed in water power	$\frac{202.7}{307.66} = 65.5$ per cent.
Efficiency of compression and transmission from the theoretical power of water to and through the motors, including cost of reheating expressed in water power.	$\frac{202.7}{329} = 61.6$ per cent.
Horse power of air at works after reheating.....	225.32
Horse power delivered to compressors by water-wheel.....	283
Theoretical horse power of water used on the wheel.....	304
Horse power of work actually done by the motors	202.7
The horse power delivered by the water-wheel to the compressor, to which is added the horse power (24.66) which the cost of the wood used in reheating would buy in water	$307.66 = 283 + 24.66$
The theoretical horse power of the water used on wheel added to the horse power (24.66) which the cost of the wood used in reheating would buy in water.....	$329 = 304 + 24.66$

It may be urged that the conditions are particularly favorable to compressed air, as the transmission is short and the power is not needed for tramways or lighting. But were it 20 miles instead of 1,000 feet, it is thought by the author that, taking the whole plant, compressor, transmission pipe, and motor, as against generator, transmission wires, transformers, and electric motors, the air will prove cheaper in first cost, higher in efficiency, less liable to accident, and less expensive to operate and maintain than by electric transmission and power.

The hydraulic power air plant of the hydraulic power company at Iron Mountain, Mich., is said to be the largest compressed-air plant in the United States. It utilizes the water-power of the Quinnesec Falls, which are 47 feet high. A separate turbine operates three duplex compressors 32 x 60 inches and one duplex compressor 36 x 60 inches, with a capac-

ity of about 16,000 cubic feet of free air per minute compressed variably from 62 to 67 pounds pressure per square inch. The compressed air is transmitted 3 miles through a 24-inch conduit, with loss in pressure of from 2 to 3 pounds per square inch, and then distributed through 1,500 feet of variable-sized pipes to hoisting engines, air pumps, rock drills, and engines for running dynamos for electric lighting.

In Fig. 77 is a reduced copy of an indicator card from an automatic Corliss engine, 10 x 30 inches, 86 revolutions, and 65 pounds pressure in the air pipe; air at normal temperature of

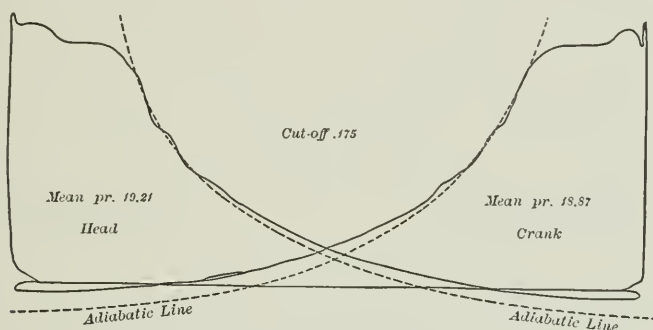


FIG 77 CORLISS ENGINE AIR CARD

70° F.; cut-off .175, which with 4 per cent clearance makes the real cut-off, as per Table XXII., .206, for which the theoretical mean pressure should be, for the air entrance pressure of 59 pounds, $73.7 \times .4369 = 32.19 - 14.7 = 17.49$ pounds, the mean pressure. By the indicator card the measured mean pressure of the head end is found to be 19.21. The dotted lines on the card show the theoretical adiabatic curve, the terminal pressure of which is shown by the formula, $73.7 \times .1041 = 7.67 - 14.7 = -6.03$. The final temperature of the exhaust should have been by the ratio for volumes from 70° F. expanded from .206 real cut-off $.5192 \times 530^\circ = 275 - 460 = -185^\circ$ F.

The ratios may be taken from Tables XVI. and XVII. for small divisional parts by interpolation; or the terminal temperature may be obtained from the equation $\left(\frac{1}{R}\right)^{.408}$. R the ratio

is $\frac{1}{.206} = 4.854 \log. 0.6861 \times .408 = 0.27992$, index of which

is 1.905 and $\frac{1}{1.905} = .5248 \times 530^\circ = 278 - 460^\circ = -182^\circ \text{ F.}$

The indicator card (Fig. 78) is from the same engines as above, with a pressure of 58 pounds in the air pipe, valve partly throttled so that the entrance pressure was but 48 pounds, and the cut-off automatically extended to .22 and the real cut-off by the clearance .25. The air was taken through a reheater and

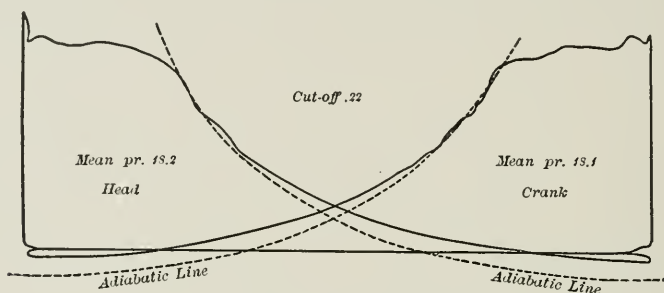


FIG. 78.—CORLISS ENGINE AIR CARD.

entered the cylinder at a temperature of 310° , making the mean pressure by measurement but slightly less than the previous card, and exhausting below the atmospheric pressure about $1\frac{1}{2}$ pounds and 6 pounds above the adiabatic theoretical line as shown by the dotted line. The final temperature as found from the ratio of expansion, which is $4 \log. 0.60206 \times .408 = 0.24564$, index 1.761, and $\frac{1}{1.761} = .5678 \times 770 = 437 - 460 = -23^\circ$.

Chapter XVII.

EFFICIENCY OF AIR COMPRESSORS AT HIGH ALTITUDES

EFFICIENCY OF AIR COMPRESSORS AT HIGH ALTITUDES.

As the density of the atmosphere decreases with the altitude, a compressor located at a high altitude takes in less air at each revolution, that is to say, the air is taken in at a lower pressure; hence the early part of each stroke is occupied in compressing the air from the lower density up to the normal sea level pressure of 14.7 pounds, and the volumetric capacity of the air cylinder is correspondingly diminished. The power required to drive the same compressor is also less than at sea level, but the decrease in power required is not in as great a ratio as the reduction in capacity. Therefore, compressors to be used at high altitudes should have the steam and air cylinders properly proportioned to meet the varying conditions at different altitudes. The compressor friction and leakage losses are a constant quantity.

It is apparent that the denser the air is when drawn into the compressor cylinder, the sooner the desired pressure is reached in terms of the cylinder stroke, and, on the contrary, the lighter or less dense the air is at the intake, the smaller will be the volume at the desired pressure, or the pressure is reached at a later point in the stroke. The volumetric efficiency of an air compressor will therefore be inversely as the mean pressure, and the loss of capacity will be the complement of the efficiency.

The air temperature at high levels is on the average lower than at sea level throughout the year, which slightly increases the density due to the height alone; so that the volumetric efficiency may be somewhat higher than is due to barometric pressure alone.

The decreased power required by a compressor due to elevation varies from 60 to 56 per cent of the loss of capacity.

The following table shows the efficiency and loss in capacity of compressors working at different altitudes, also the approximate decrease in power required as compared with the same compressor working at sea level, and delivering air at 70 pounds pressure per square inch:

TABLE XXXIII.—COMPRESSOR EFFICIENCIES AT DIFFERENT ALTITUDES.

Altitude, feet.	BAROMETRIC PRESSURE.		Volumetric efficiency of compressor, per cent.	Loss of capacity, per cent.	Decreased power required, per cent.
	Inches, mercury.	Pounds per square inch.			
0	30.00	14.75	100	0	0.
1,000	28.88	14.20	97	3	1.8
2,000	27.80	13.67	93	7	3.5
3,000	26.76	13.16	90	10	5.2
4,000	25.76	12.67	87	13	6.9
5,000	24.79	12.20	84	16	8.5
6,000	23.86	11.73	81	19	10.1
7,000	22.97	11.30	78	22	11.6
8,000	22.11	10.87	76	24	13.1
9,000	21.29	10.46	73	27	14.6
10,000	20.49	10.07	70	30	16.1
11,000	19.72	9.70	68	32	17.6
12,000	18.98	9.34	65	35	19.1
13,000	18.27	8.98	63	37	20.6
14,000	17.59	8.65	60	40	22.1
15,000	16.93	8.32	58	42	23.5

For pressures above 70 pounds as given in above table, deduct 3 per cent from the tabulated figures in column 4 and 10 per cent in column 6 for each 10 pounds approximate.

CAPACITY OF AIR COMPRESSORS.

To ascertain the capacity of an air compressor in cubic feet of free air per minute, the common practice is to multiply the area of the intake cylinder by the feet of piston travel per minute. The free air capacity of the compressor divided by the number of atmospheres will give the volume of compressed air per minute. To ascertain the number of atmospheres at any given pressure, add 15 pounds to the gauge pressure, divide this sum by 15, and the result will be the number of atmospheres.

The above method of calculation, however, is only theoretical, and these results are never obtained in actual practice even

with compressors of the very best design. Allowances should be made for losses of various kinds, the principal loss being due to clearance spaces; but in machines of poor design and construction other considerable losses occur through imperfect cooling, leakages past the piston and through the discharge valves, and insufficient area and improper working of inlet valves. We have seen compressors in which the total air loss was from 10 to 20 per cent, whereas 3 to 10 per cent should be the maximum—according to size—in compressors of best design and construction.

The following table will be found useful for ascertaining quickly the capacity of an air compressor, also to find the cubical contents of any cylinder or receiver.

The first column is the diameter of the cylinder in inches, the second shows the cubical contents, in feet, for each foot in length. To find the capacity of an air cylinder, multiply the figure in the second column by the piston travel in feet per minute; this applies to double-acting air cylinders; in the case of single-acting air cylinders the result should be divided by 2.

TABLE XXXIV.—CONTENTS OF CYLINDER IN CUBIC FEET FOR EACH FOOT IN LENGTH.

Diam. inches.	Cubic contents.	Diam. inches.	Cubic contents.	Diam. inches.	Cubic contents.	Diam. inches.	Cubic contents.	Diam. inches.	Cubic contents.
1	.0055	5 $\frac{3}{4}$	.1803	10 $\frac{1}{2}$	.6013	18 $\frac{1}{2}$	1.867	31	5.241
1 $\frac{1}{4}$	.0085	6	.1963	10 $\frac{3}{4}$	.6303	19	1.969	32	5.585
1 $\frac{1}{2}$	.0123	6 $\frac{1}{4}$	.2130	11	.6600	19 $\frac{1}{2}$	2.074	33	5.940
1 $\frac{3}{4}$	.0168	6 $\frac{1}{2}$	.2305	11 $\frac{1}{4}$	.6903	20	2.182	34	6.305
2	.0218	6 $\frac{3}{4}$	.2485	11 $\frac{1}{2}$	.7213	20 $\frac{1}{2}$	2.292	35	6.681
2 $\frac{1}{4}$	.0276	7	.2673	11 $\frac{3}{4}$	.7530	21	2.405	36	7.069
2 $\frac{1}{2}$	.0341	7 $\frac{1}{4}$	.2868	12	.7854	21 $\frac{1}{2}$	2.521	37	7.468
2 $\frac{3}{4}$	.0413	7 $\frac{1}{2}$	.3068	12 $\frac{1}{2}$	.8523	22	2.640	38	7.886
3	.0491	7 $\frac{3}{4}$	.3275	13	.9218	22 $\frac{1}{2}$	2.761	39	8.296
3 $\frac{1}{4}$	.0576	8	.3490	13 $\frac{1}{2}$	.9940	23	2.885	40	8.728
3 $\frac{1}{2}$	.0668	8 $\frac{1}{4}$	.3713	14	1.069	23 $\frac{1}{2}$	3.012	41	9.168
3 $\frac{3}{4}$	.0767	8 $\frac{1}{2}$	.3940	14 $\frac{1}{2}$	1.147	24	3.142	42	9.620
4	.0873	8 $\frac{3}{4}$	.4175	15	1.227	25	3.409	43	10.084
4 $\frac{1}{4}$	.0985	9	.4418	15 $\frac{1}{2}$	1.310	26	3.687	44	10.560
4 $\frac{1}{2}$	.1105	9 $\frac{1}{4}$	.4668	16	1.396	27	3.976	45	11.044
4 $\frac{3}{4}$	.1231	9 $\frac{1}{2}$	.4923	16 $\frac{1}{2}$	1.485	28	4.276	46	11.540
5	.1364	9 $\frac{3}{4}$	.5185	17	1.576	29	4.587	47	12.048
5 $\frac{1}{4}$	.1503	10	.5455	17 $\frac{1}{2}$	1.670	30	4.909	48	12.566
5 $\frac{1}{2}$	.1650	10 $\frac{1}{4}$	.5730	18	1.767				

COMPRESSED AIR FOR HOISTING ENGINES.

The following table is intended to give an approximate idea of the volume of free air required for operating hoisting engines, the air being delivered to the engines at 60 pounds gauge pressure. There are so many variable conditions to the operation of hoisting by the hoisting engines in common use that accurate computations can only be offered when fixed data are given. In the table, the hoisting engine is assumed to actually run but one-half of the time for hoisting, while the compressor, of course, runs continuously. If the engine run less than one-half the time, as it usually does, the volume of air required will be proportionately less, and *vice versa*. The table is computed for maximum loads, which also in practice may vary widely. From the intermittent character of the work of a hoisting engine the parts are able to resume their normal temperature between the hoists, and there is little probability of the annoyance of freezing up the exhaust passages.

TABLE XXXV.—VOLUME OF FREE AIR REQUIRED PER MINUTE FOR OPERATING HOISTING ENGINES, THE AIR COMPRESSED TO 60 POUNDS GAUGE PRESSURE.

Single Cylinder Hoisting Engine.

Diameter of cylinder, inches.	Stroke, inches.	Revolutions per minute.	Normal horse-power.	Actual horse-power.	Weight lifted, single rope.	Cubic feet of free air required.
5	6	200	3	5.9	600	75
5	8	160	4	6.3	1,000	80
6¼	8	160	6	9.9	1,500	125
7	10	125	10	12.1	2,000	151
8¼	10	125	15	16.8	3,000	170
8½	12	110	20	18.9	5,000	238
10	12	110	25	26.2	6,000	330

Double Cylinder Hoisting Engine.

5	6	200	6	11.8	1,000	150
5	8	160	8	12.6	1,650	160
6¼	8	160	12	19.8	2,500	250
7	10	125	20	24.2	3,500	302
8¼	10	125	30	33.6	6,000	340
8½	12	110	40	37.8	8,000	476
10	12	110	50	52.4	10,000	660
12¼	15	100	75	80.2	.....	1,125
14	18	90	100	125.	.....	1,587

TABLE XXXVI.—COMPRESSED AIR REQUIRED FOR PUMPING WATER, INCLUDING ALLOWANCE FOR CLEARANCE IN PUMP AND FRICTION
(Ingersoll-Sergeant Drill Co.)
IN PIPE.

Ratio of diam- eters.	PERPENDICULAR HEIGHT, IN FEET, TO WHICH THE WATER IS TO BE PUMPED.															
	25.	50.	75.	100.	125.	150.	175.	200.	225.	250.	300.	350.	400.	450.	500.	
1 to 1 }	13.75	27.5	41.25	55.0	68.25	82.5	96.25	110.0	....	....	....	....	....	....	....	Air pressure at pump.
	0.21	0.45	0.60	0.75	0.89	1.04	1.20	1.34	....	....	....	....	....	....	....	Cubic feet of free air per gallon of water.
1½ to 1 }		12.22	18.33	24.44	30.33	36.66	42.76	48.88	55.0	61.11	73.32	85.4	97.66	....	....	Air pressure at pump.
		0.65	0.80	0.95	1.09	1.24	1.39	1.53	1.68	1.83	2.12	2.41	2.70	....	....	Cubic feet of free air per gallon of water.
1¾ to 1 }			13.75	19.8	22.8	27.5	32.1	36.66	41.25	45.83	55.0	64.16	73.33	82.5	....	Air pressure at pump.
			0.94	1.14	1.24	1.30	1.54	1.69	1.84	1.99	2.39	2.59	2.88	3.19	....	Cubic feet of free air per gallon of water.
2 to 1 }				13.75	17.19	20.63	24.06	27.5	30.94	34.38	41.25	48.13	55.0	61.88	68.75	Air pressure at pump.
				1.23	1.37	1.52	1.66	1.81	1.96	2.11	2.40	2.69	2.98	3.28	3.57	Cubic feet of free air per gallon of water.
2¼ to 1 }					13.75	16.5	19.25	22.0	24.75	27.5	33.0	38.5	44.0	49.5	55.0	Air pressure at pump.
					1.53	1.68	1.83	1.97	2.12	2.26	2.56	2.85	3.15	3.44	3.73	Cubic feet of free air per gallon of water.
2½ to 1 }						13.2	15.4	17.6	19.8	22.0	26.4	30.8	35.2	39.6	44.0	Air pressure at pump.
						1.79	1.98	2.06	2.10	2.34	2.62	2.88	3.18	3.36	3.23	Cubic feet of free air per gallon of water.

To find the amount of air and pressure required to pump a given quantity of water a given height, find the ratio of diameters between water and air cylinders, and multiply the number of gallons of water by the figure found in the column for the required lift. The result is the number of cubic feet of free air. The pressure required on the pump will be found directly above in the same column. For example: The ratio between cylinders being 2 to 1. Required to pump 100 gallons, height of lift 250 feet. Find under 250 feet at ratio 2 to 1, the figures 2.11: then $2.11 \times 100 = 211$ cubic feet of free air for the time required to lift the water, or per minute for both water and air. The pressure required is 34.38 pounds.

TABLE XXXVII.—VOLUME OF AIR AND PRESSURE REQUIRED TO DRIVE DIRECT-ACTING STEAM PUMPS. (F. C. Weber.)

Head of water in feet.	GAUGE PRESSURES IN POUNDS PER SQUARE INCH.							CUBIC FEET OF FREE AIR PER MINUTE TO LIFT ONE GALLON OF WATER.						
	Ratio of Cylinder Diameters.							Ratio of Cylinder Diameters.						
	1 to 1.	1¼ to 1.	1½ to 1.	1¾ to 1.	2 to 1.	2½ to 1.	3 to 1.	1 to 1.	1¼ to 1.	1½ to 1.	1¾ to 1.	2 to 1.	2½ to 1.	3 to 1.
10	6	...	...	...	...	...	...	.22						
20	11	7	...	...	...	...	...	.28	.37					
30	16	10	7	...	...	...	...	.33	.42	.53				
40	21	13	9	7	...	...	...	.38	.47	.58	.72			
50	26	17	12	9	7	...	...	.44	.53	.65	.79	.94		
60	31	20	14	10	8	...	...	.49	.58	.70	.82	.99		
70	36	23	16	12	9	...	...	.54	.63	.75	.88	1.03		
80	42	26	18	14	11	...	...	.61	.68	.79	.95	1.11		
90	47	30	21	15	12	...	...	.66	.75	.87	.98	1.15		
100	52	34	23	17	13	...	...	.72	.82	.91	1.05	1.20		
125	65	42	29	21	16	10	...	.86	.95	1.06	1.18	1.33	1.67	
150	78	50	35	25	20	13	9	1.00	1.08	1.20	1.31	1.50	1.88	2.31
175	90	58	40	30	23	15	10	1.12	1.22	1.32	1.47	1.63	2.00	2.40
200	105	67	46	34	26	17	12	1.28	1.37	1.47	1.60	1.75	2.14	2.60
250	...	83	58	42	33	21	15	...	1.64	1.75	1.86	2.06	2.41	2.89
300	...	100	68	50	39	25	17	...	1.92	2.00	2.12	2.31	2.68	3.08
350	...	...	80	58	45	29	20	...	...	2.28	2.39	2.57	2.95	3.37
400	...	...	92	67	52	33	23	...	...	2.57	2.68	2.87	3.22	3.66
450	...	...	105	75	58	37	26	...	...	2.88	2.94	3.13	3.48	3.95
500	...	...	...	85	65	42	29	...	...	...	3.27	3.42	3.82	4.24
600	...	...	...	100	78	50	35	...	...	...	3.76	4.00	4.35	4.80
700	...	...	...	...	92	60	42	...	...	...	...	4.58	5.00	5.50
800	...	...	...	...	105	67	47	...	...	...	...	5.15	5.50	5.96
900	...	...	...	...	...	75	52	...	...	...	...	...	6.00	6.45
1,000	...	...	...	...	...	85	58	...	...	...	...	...	6.70	7.00

To find the quantity of free air required per minute, in a direct-acting steam pump, to raise a given number of gallons of water through a given head, divide the diameter of air cylinder by the diameter of water cylinder, and under the heading of this ratio in above table and to the right of the given head or lift find the cubic feet of free air per gallon required per minute; this constant multiplied by the total number of gallons to be lifted will give the quantity of free air required. The *gauge pressure* for the corresponding conditions can be found in a similar manner under the heading of gauge pressures.

In the above table of pressures an allowance of 15 per cent has been made for pump friction, and in the table of volumes 15 per cent has also been allowed for clearance losses and leakage. If the air is reheated before admission to air cylinder the quantity may be reduced in proportion to the ratio of absolute temperatures. For compound pumps the consumption may be assumed at 75 per cent of the best results of the above table.

To find the amount of air required to drive any steam pump under any head of water: Divide the diameter of the air cylinder by the diameter of the water cylinder, find the ratio in the first column of Table XXXVIII., follow the line of figures to the right until the column is reached which is headed by the head of water to be pumped against. At this point will be found a constant which, multiplied by the area of the air piston in square inches, will give the cubic feet of free air consumed by the pump per minute, at 100 feet piston speed per minute.

AIR VOLUMES USED IN ENGINES AND MOTORS.

The present increasing demand for the use of compressed air as a motive power necessarily involves the use of intricate mathematical formulæ for estimating relative sizes of compressors and air engines.

Quite a number of these formulæ have been worked out to cover average practical conditions and are daily serving a very useful purpose in the form of tables.

A very intricate formula is the one based upon the use of free air per minute per indicated horse power in an air engine, and as a problem is often stated in terms of the I. H. P. of the motor—to find the quantity of free air per minute required; the following table will facilitate computations of this kind and is in such shape that it will not require any extended knowledge of mathematics:

TABLE XXXIX.—AIR USED IN CUBIC FEET FREE AIR PER MINUTE, PER I. H. P. IN MOTORS (WITHOUT REHEATING).

Point of cut-off.	GAUGE PRESSURES.										
	30.	40.	50.	60.	70.	80.	90.	100.	110.	125.	150.
1	23.3	21.3	20.2	19.4	18.8	18.42	18.10	17.8	17.62	17.40	17.05
	18.7	17.1	16.1	15.47	15.0	14.6	14.35	14.15	13.98	13.78	13.50
	17.85	16.2	15.2	14.50	14.2	13.75	13.47	13.28	13.08	12.90	12.60
	16.4	14.5	13.5	12.8	12.3	11.93	11.7	11.48	11.30	11.10	10.85
	17.5	15.2	12.9	11.85	11.26	10.8	10.5	10.21	10.02	9.78	9.50
	20.6	15.6	13.4	13.3	11.40	10.72	10.31	10.0	9.75	9.42	9.10

As will be seen from the table, the only data required are the gauge pressure and point of cut-off; having those two items given, we find from the table the free air required per I. H. P., and it will only be necessary to multiply this amount by the total I. H. P. of the motor to determine the total quantity of free air required and consequently the size of an air compressor to furnish the air.

These figures do not take account of clearance, but it will be an easy matter to add the *per cent* of clearance after having determined the total amount of free air required.

It will also be noticed that the free air consumption is based upon the use of cold air, *i.e.*, initial temperature of air at 60° F. In case reheating is resorted to there will be a corresponding decrease in the amount used depending upon the temperature of air at admission to motor, and will be proportional to the ratio of $\frac{T_2}{T_3}$ where $T_2 = 460 + 60 = 520^\circ$ F. absolute temperature and $T_3 = 460 +$ temperature of air at admission to motor.

Thus if the air is reheated to 300° F., the quantity in the table will have to be multiplied by $\frac{460 + 60}{460 + 300} = \frac{520}{760} = .684$.

A further use of this table is to find the most economical point of cut-off for gauge pressures from 30 pounds to 150 pounds per square inch. This fact is apparent from a study of each vertical column; thus, at 60 pounds pressure, the lowest consumption of free air per I. H. P. is at $\frac{1}{3}$ cut-off, while a 40 pounds pressure will work most economically at $\frac{1}{2}$ cut-off.

—F. C. Weber in "*Compressed Air*."

METER MEASUREMENT OF COMPRESSED AIR.

The renting of air power caused by the rapidly extending use of compressed air requires, for measuring the quantity used by an air tenant, a means that is reliable within a small fraction of error. The measurement of water power is well established, but the measurement of steam power, except by the indicator, is but little practised by a meter.

The needed measurements of the flow of natural gas to consumers at pressures beyond the capacity of the ordinary gas meter has led to the construction of a meter suitable for the measurement of the flow of compressed air for any pressure up to 500 pounds per square inch. The Equitable Meter Company, Pittsburg, Pa., have made a study of meters for compressed air for a number of years with successful results. Their meters, which we illustrate, are made in five sizes as follows: 10, 20, 30, 40, and 50 thousand cubic feet maximum capacity per hour.

The method of measurement is by the amount of air in cubic feet at the pressure at which it passes through the meter, no matter if the air pressure is 1 pound or 100 pounds to the square inch; and then, to find the total volume of free air passed, the volume of compressed air will have to be reduced into a volume of free air.

This may be readily done by multiplying the meter index measurement in cubic feet by the ratio of isothermal compression in column 3, Table XVII., in this work. There is very little friction in the meter mechanism, amounting to only about one ounce absorption in pressure under any pressure passing through the meter. The meter is also provided with a relief

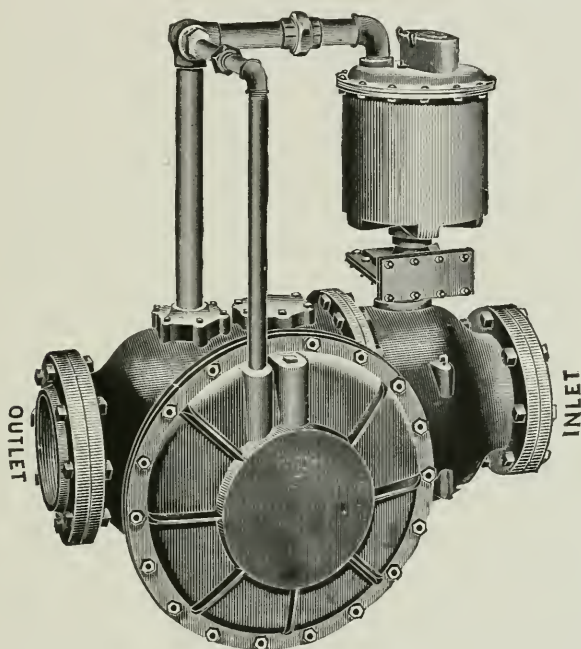


FIG. 79 —THE AIR METER.

valve to guard against wreckage of the meter mechanism by a sudden change of pressure on its two sides by accident.

As the installation of compressed-air central plants for distributing power is gaining daily in importance, the problem of measuring the amount of compressed air at certain pressures used by any consumer confronts not only the central plant owners, but also the consumer. The consumer should know how much air he uses in order to know that he is charged reasonably for it, and the central plant owners must also know how much every consumer uses in order to avoid abuse and to ascertain whether the plant is operated on a paying basis.

Thus the central plant owners, having a main supply pipe which may be branched off for distributing to mines or manufacturing establishments, will find the necessity of installing meters and other apparatus which cannot be tampered with, and which at the end of each month will be able to give not only themselves, but also the consumer, proper data from which the bills for the month can be figured.

The only way properly to determine the amount of compressed air used by any single consumer is to determine the amount of free air, which, if multiplied by the mean average pressure, will give the total amount of energy furnished.

The next question of importance to be considered is for both producer and consumer to know that the air pressure is as steady as possible, and sufficient to run the apparatus to be operated by compressed air, as there would be no use for a consumer to pay for a larger volume of compressed air at 50 pounds pressure should he require 80 pounds pressure, as a large quantity of air at a low pressure would not do his work; thus it would be necessary to install a compressed-air-pressure recording gauge in connection with each meter, and at the end of the month the mean average pressure could be figured; and this, multiplied by the number of cubic feet of free air, the product representing the energy furnished, would enable both producer and consumer to settle upon the amount to be paid.

The problem has been explained clearly enough, but it may be added, however, that it would always be advisable to install a small receiver next to the meter, and that the pressure recording gauge should be connected with this receiver; this, not only to avoid vibration of the recording finger, but also to prevent any shock to the meter.

It should be noted also that a consumer situated far away from the central power plant should pay more per unit of energy than one near by, for the reason that the friction in long pipes amounts to a certain percentage of power, and that a long pipe line is more subject to leaks and requires more attention than a short one.

Chapter XVIII.

AIR COMPRESSORS

AIR COMPRESSORS.

ONE of the earliest compressed-air devices was the trompe or hydraulic air blast for forges. Its capacity was sufficient for the wants of the times, which made it the principal means for furnishing a steady blast for the Catalan forges of the early

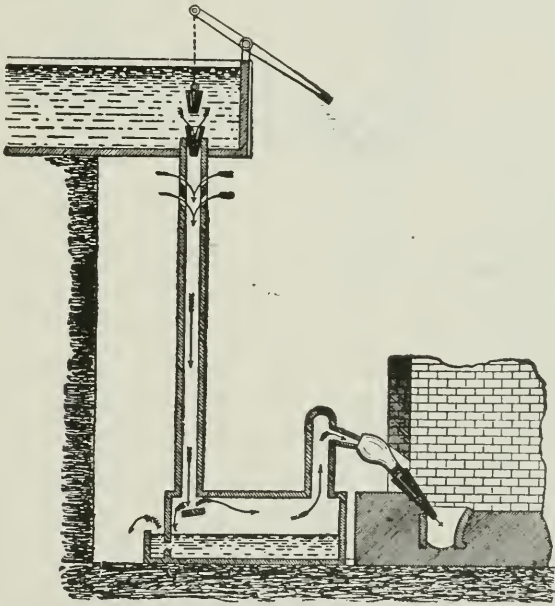


FIG. 80.—THE TROMPE.

years of the iron age. It could produce a pressure from an ounce to one pound or more, according to the height of the water shaft and the depth of the water seal. In the trompes of the best construction the water seal was a sliding gate which could be operated to produce any desired pressure within the range of the apparatus. Its operation was as follows (Fig. 80): the falling column of water draws in air through the small inclined orifices as shown by the arrows, carrying it into the

reservoir where it separates, and is discharged through the tuyère pipe. The outlet discharges the water through an inverted siphon, carried high enough to balance the air pressure.

In the principles of the trompe is found a correspondence and suggestion of the experiments made by J. P. Frizell in

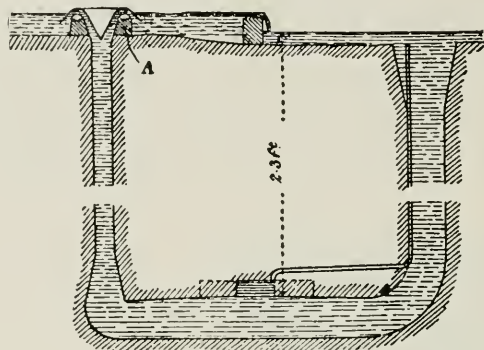


FIG. 81.—THE FRIZELL SYSTEM.

1877, and since carried out on a larger scale by C. H. Taylor in the practical hydraulic air compressors at Magog, Quebec, and at Ainsworth, B. C.

Many experiments have been made to compress air by the direct and injector system for small quantities, by the use of water under pressure from city water supply.

By direct pressure it requires an equal quantity of water to the volume of free air compressed to nearly the same pressure as the water. By the injector system, the only available experiments are those of M. Romally, in France, who found that with 35 feet head only 46 per cent of the volume of the water used was equal to the volume of free air at a pressure of 21 pounds per square inch; thus realizing an air pressure of 138 per cent of the hydraulic head and less than one-half the volume, an efficiency of about 63 per cent.

Mr. Frizell's experiments involved a large outlay in cost of plant, and where there is a moderate water-fall and plenty of water this is no doubt the cheapest working method of compressing air. The general idea of Mr. Frizell was to utilize a

high water-fall with built-up shafts and air chamber, or with a low water-fall to sink shafts with an air-gathering chamber at the bottom and air pipe leading to the surface as shown in Fig. 81. The entrance at *A* in the cut was a circular hollow dam with a conical inlet. The annular chamber under the dam communicated with the outer air and was perforated, so that the falling water drew down the air and by its velocity carried the air to the receiving chamber below. This suggestion and experiments lay in abeyance under the Frizell patent for many years, and was supplemented by a similar patent to Mr. George Waring. The efficiency in Frizell's early experiments was 26 per cent of the fall of water used in the apparatus. Later improvements by him raised the efficiency to 52 per cent with a head of 5 feet.

The hydraulic compressor system of Mr. Taylor is illustrated in Figs. 82 and 83, in which a large number of small air tubes are distributed around an annular water inlet to the down-flow pipe. One of its several forms of construction is shown in Fig. 82, and more fully illustrated in Figs. 84 and 85.

A number of air tubes, *c, c*, terminate at the conical entrance of the down-flow pipe, *B*, at *a, a*, Fig. 82. A supply of water to the chamber *A, A*, and its flow down the pipe, draws air through the small pipes, carrying it down to the separating tank, *c, c*, where it is liberated at the pressure due to the hydrostatic head. The air is delivered through a pipe, as shown in the cut, and the water rises through a pipe or open shaft to the tail race.

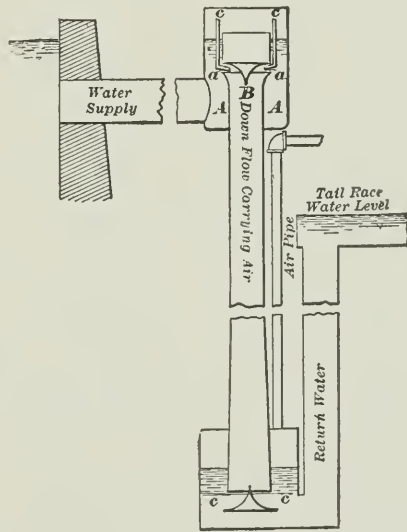


FIG. 82.—THE TAYLOR HYDRAULIC AIR COMPRESSOR.

The compressor as erected at Magog, Quebec, gives in air power 62 per cent of the water power used and delivers 155 horse power in compressed air at 52 pounds gauge pressure.

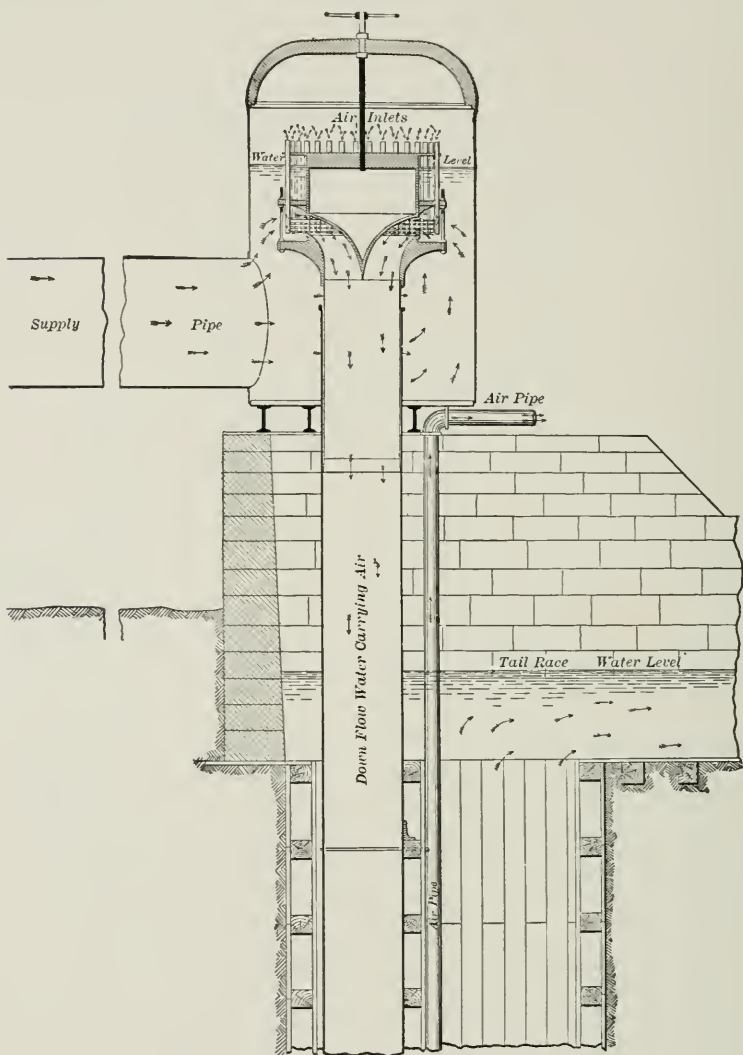


FIG. 83.—HYDRAULIC AIR COMPRESSOR.

Magog, Quebec. Air head section.

A most remarkable feature of this system is that, notwithstanding that the air is compressed by the weight of the water and in actual contact with it, the air so compressed is delivered

in the receiver and thence to the transmission pipe drier than when drawn in from the atmosphere.

At first sight this would seem impossible, but it is well known that in a high temperature moisture is held longer in air than in a lower temperature, hence the contact of the air globules with the cold water keeps down the temperature usually caused by the compression of air, and the atmospheric moisture held in the globules condenses, as it were, on the walls of these globules, and at the point of separation the air and water are absolutely separated, leaving the air all ready for distribution at the same temperature as the water it has just left, and drier than when first taken in through the small air pipes.

Another feature is that the power of the water can be converted into compressed air at any pressure per square inch, giving the same efficiency at either high or low pressure with a far less loss of energy than by any other process of transforming a water power into transmittable force, and with unvarying pressure.

Should the volume of air taken down be greater than that being used, it accumulates in the receiver until it forces the water below the lower end of the receiver, and the surplus passes up with the return water, thereby forming a perfectly automatic safety-valve, without requiring any attendance whatever. It will be observed that the material used in the construction of the down-flow pipe need only be of sufficient strength to carry the weight of water and pressure generated in the working head of the water power, as once it reaches the tail-race level the internal pressure is gradually neutralized from that point down by the pressure in the return water surrounding the down-flow pipe; so that any pressure almost may be reached without increasing the strength of the down-flow pipe. The material for the down-flow pipe may be of iron, or wood hooped with iron, and the shaft may be constructed of the cheapest of timber; and as it is preserved by being con-

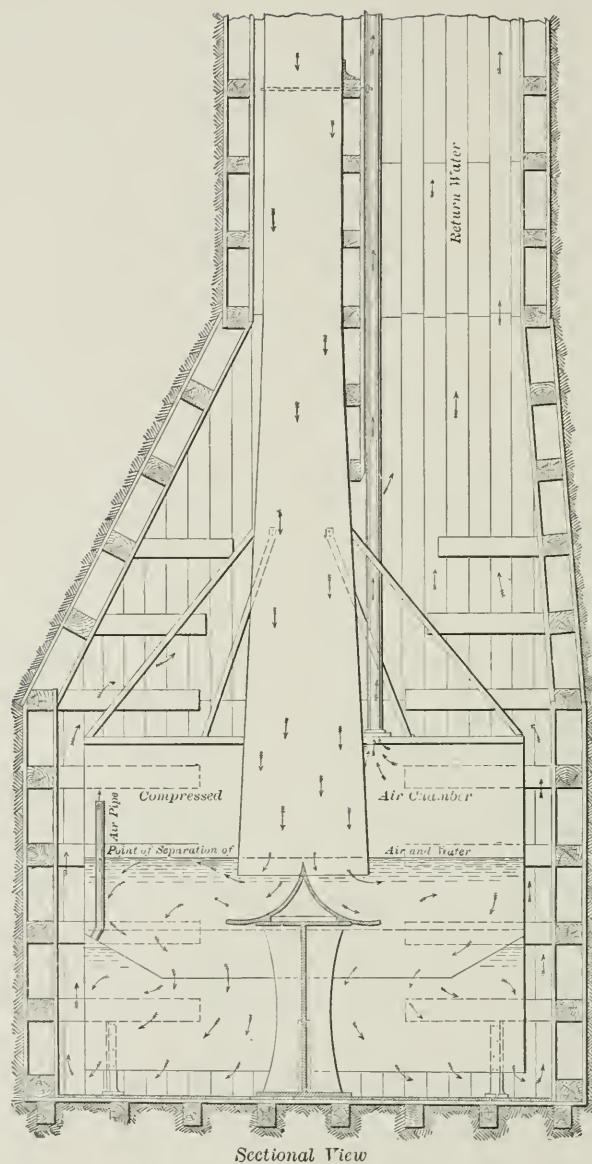


FIG. 84.—HYDRAULIC AIR COMPRESSOR.

Magog, Quebec. Air chamber section.

stantly in the water, there is practically no limit to its durability.

By this system low falls, otherwise useless, may be utilized, and the same pressure obtained as from high falls, the horse power being determined by the diameter of the down-flow pipe, and the height and volume of water in the fall, while the pressure depends solely upon the depth of the well or shaft; therefore any desired pressure can be obtained.

In the apparatus at Magog, Quebec, the receiver is sufficiently large in diameter to allow the air to rise to the surface

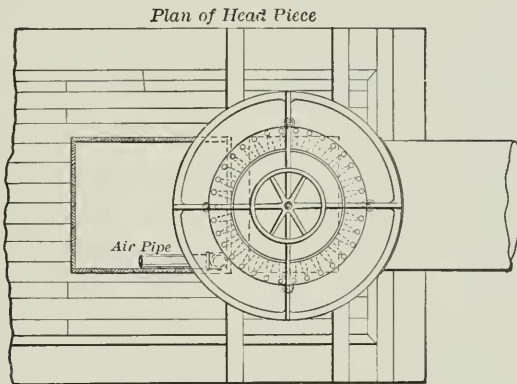


FIG. 85—PLAN OF AIR TUBES.

of the water therein, from whence it is taken through the air pipe for transmission to be utilized as power or for other purposes. The water, being kept down by the pressure of the air, is forced out through the open bottom of the receiver and up the shaft around the down-flow pipe to the tail-race level.

The compressor is so constructed as to permit of its being regulated to furnish any proportion—from one-third of its capacity—using water proportionately with a like efficiency.

By reference to the head section (Fig. 83) it will be noticed that the head piece is telescoped into the down-flow pipe, and raised or lowered by means of a hand-wheel on top, thus permitting the flow of water to be regulated, or to lift it above the

water level and stop entirely the flow of air, the water being regulated by the head gate.

Briefly stated, the air is compressed by the direct pressure of falling water without the aid of any moving machinery, and practically without expense for maintenance or attendance after installation.

By this system any fall of water varying in working head may be utilized, and any pressure required can be produced and uniformly maintained up to the capacity of the water power, delivering the compressed air at the temperature of the water, and in a drier state than is possible by any known means of compression, thereby avoiding all loss by condensation or shrinkage by cooling of the air after compression.

The water may be conveyed to the compressor by means of an open flume; or, as shown in the diagram, through a pipe supplying a tank or stand-pipe around the headpiece of the compressor, where it can attain the same level as the water in the dam or source of supply.

Around the head-piece are placed a large number of small, horizontal air pipes, drawing their supply of air through larger vertical pipes, which extend above the surface of the water and open to the atmosphere.

As the water enters the down-flow pipe and passes the ends of these small air pipes, it draws in the air in the form of small uniform globules, which, becoming entangled in the descending water, are carried down to the receiver at the bottom of the pipe, compressing the air by the pressure of the water surrounding these globules until they reach the point of separation. This pressure is maintained so long as there remains any air in the receiver chamber.

The enlargement of the down-flow pipe at the bottom section was made to lessen the velocity of the water and air at that point, which was found to facilitate the separation of the air from the water by coalescing the small globules of air and the better separation at the deflecting plate below. The deflecting

plate prevents the plunge of the down-flowing water into the separating part of the tank and by its deflections gives the air a more ready separation from the water. By this arrangement no air was found in the water discharge pipe.

In tests of efficiency it has been found that the gross power of the water passing through the compressor due to its natural fall was 158 horse power, of which 111 horse power was utilized in the work of air compression, giving an efficiency of 70 per cent of the gross power used.

Later experiments indicate that an efficiency of 75 per cent may be obtained by a modification of the air inlet pipes and water head.

In Fig. 86 is illustrated the Taylor hydraulic air-compressing plant at Ainsworth, B. C., which was established in a trussed tower in order to carry up the air head to a level with the flume, of which Fig. 86 represents the elevation and arrangement of the head. The available working head from the water level in the head stock to the tail race is 102 feet; the depth of the shaft is 210 feet, and the depth of the air chamber at the bottom of the shaft is 17 feet, from which the water closure of the down-flow tube leaves 200 feet as the available hydrostatic pressure, which gives an air pressure of 87 pounds per square inch. The flume supplying water from Coffee Creek, 1,350 feet distant, is 5 feet in diameter, of stave-barrel construction. The tower head is also of wood staves, is 12 feet in

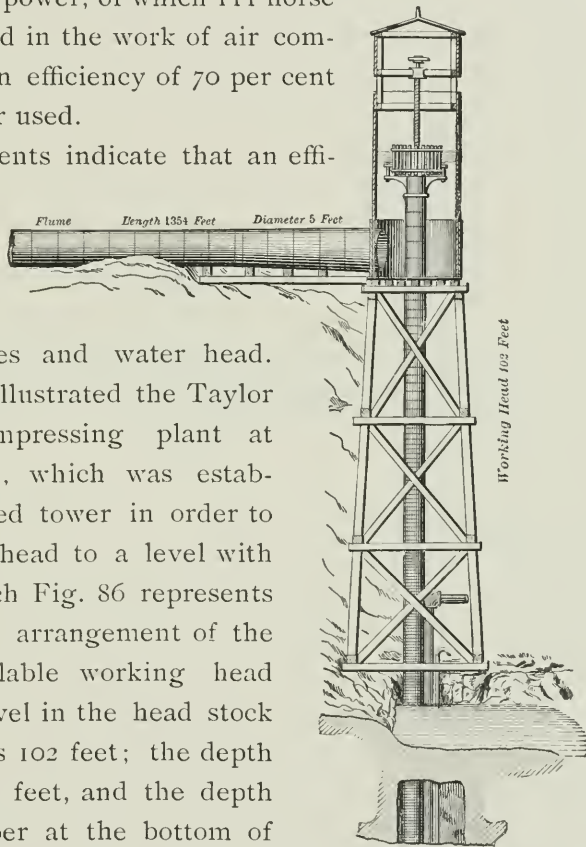


FIG. 86.—HYDRAULIC AIR COMPRESSOR.

Ainsworth, B. C.

diameter and 20 feet high. The down-flow pipe is of the same construction, 2 feet 9 inches in diameter, widening slightly at the bottom to retard the velocity of the descending water and allow it to impinge upon a whorling cone that produces a circling current in the air chamber that facilitates the separation of the compressed air from the water. The air rises to the top of the separating chamber and is delivered through a 9-inch pipe to the various branches for air distribution at the ground surface. A secondary pipe is carried from midway in the separating chamber to the surface above the tail race that seals the air space with water when the air is being used in excess of

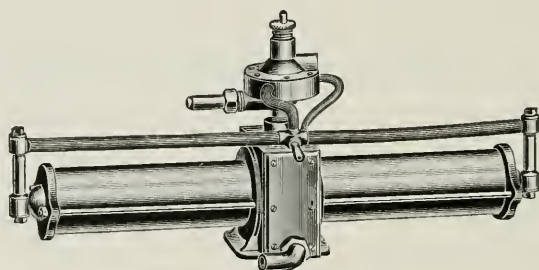


FIG. 87.—HARTFORD AIR COMPRESSOR.

compression, and allows the air to escape when it accumulates and pushes the water surface below the mouth of the air pipe; thus making an air-pressure regulator within the limit of one-pound air pressure.

The regulation of the air-inlet pipes, of which there are about three thousand tubes, $\frac{3}{4}$ -inch diameter and the conical adjutage, is made by raising or lowering the air pipes and cone by a screw and wheel, as shown in Fig. 86. The velocity of the water in the down-flow pipe is about 34 feet per second, and the velocity of the indraft of air is nearly the same. The air is received by the water in millions of globules, which in a great measure retain their individuality, gradually becoming smaller by the increasing water pressure until they are liberated in the air chamber below.

The air intake is estimated at 5,000 cubic feet of free air

per minute, and at 85 pounds pressure should develop nearly 500 horse power.

The air plant has a distributing system of over 11,000 feet of pipe of varying sizes in use in a number of mines. The air is unusually dry, and the drills and hoists have no trouble from frosted exhausts.

The hydraulic air compressor of the L. E. Rhodes Company, Hartford, Conn. (Fig. 87), consists of two displacement cylinders with alternating water valves to control the operation of the compressor. It operates by water pressure from any water-works supply, and will compress an equal volume of free air to the volume of water used, to nearly the same pressure as the water supply. It is a most convenient apparatus for supplying compressed air for dental air tools, spraying, and for many uses where a small quantity of compressed air is required in experimental and laboratory work. In Fig. 88 is illustrated the vertical differential compressor, in which a larger volume of air, in proportion to the water used, is obtained at lower pressure than that of the water by the differential area of the pistons.

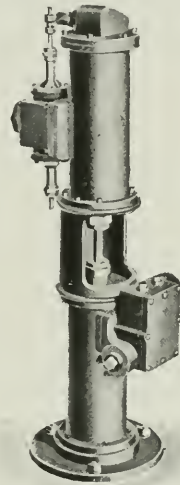


FIG. 88.—VERTICAL COMPRESSOR.

A direct-acting hydraulic air compressor was used at the Mont Cenis tunnel, using a mountain stream giving a head of 85 feet. A number of compressors were installed on this principle by Sommeiller, which gave satisfactory results at that time, owing to the favorable location of the mountain stream. This idea has been followed since by many patents on direct-acting hydraulic air compressors. The want of favorable locations where high pressure and volume can be obtained has caused this system to be neglected.

This was followed by the Darlington hydraulic piston compressor, illustrated in Fig. 89, which was designed somewhat after the model of the Sommeiller, using water for a piston,

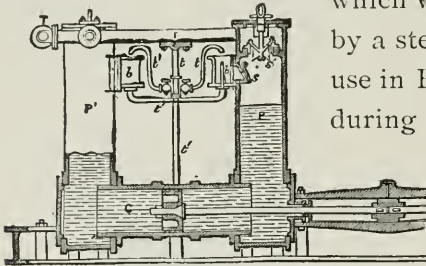


FIG. 89.—DARLINGTON COMPRESSOR.

which was operated by a piston driven by a steam engine. It was much in use in France, Germany, and Belgium during the earlier period of air compression for practical work, but was soon superseded by the modern designs. Its action was as follows: A reciprocating piston in the

water cylinder, *G*, produces an oscillating motion in the water of the two vertical cylinders, drawing in air through the flap valves at the side, and discharging the compressed air through the valves at the top. The water pipes, *t, t, t*, are to supply the place of water ejected through the air valve by delivering all the air compressed at each stroke of the piston.

A further advance in air-compressor design seems to have been made in the model of the Dubois and François compressors, which was intended to improve on the slow work of the Sommeiller compressors by charging the cylinder with no more water than would fill the valve chambers, and inserting water jets for cooling the air during compression, and to supply the waste by carrying part of the water through the exit valves.

In this design the practical operation and speed seemed a great advance over the former designs, and for a time seemed to take a leading place for air compression in France and Germany.

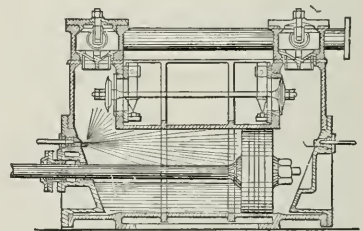


FIG. 90.—DUBOIS AND FRANÇOIS COMPRESSOR.

In the mean time progress was being made in England and

the United States by reducing the cylinder clearance, and with only a small spray for cooling effect and for balancing the unequal effect of the steam impulse and the air resistance, when steam was used expansively and for its best economy. The first efforts were by placing the steam and air cylinder at a right angle and operating through angular cranks. This arrangement used in the Burleigh and early Ingersoll type is sketched in Fig. 91, in which the cylinders were set at 90° and the cranks at 30° . This plan was also used

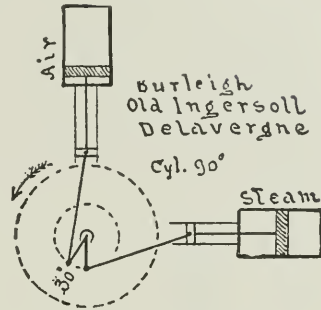


FIG. 91.—TYPE.

by Delavergne for ammonia compressors, and is still in use by the Frick Company and others for ammonia.

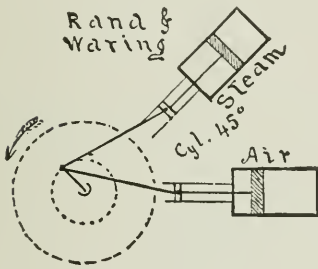


FIG. 92.—TYPE.

Another form of construction by Rand and Waring was in use in 1872, and is shown in sketch (Fig. 92). The steam cylinder was placed over the air cylinders at an

angle of 45° , and connected to a single crank. This form made a fairly compact arrangement of frame, and in a measure equalized the steam and air pressures. Davies in England also worked on these ideas and built compressors with cylinders at an angle of 135° and connected to a single crank (Fig. 93). It was early perceived that an angular position of the cylinders

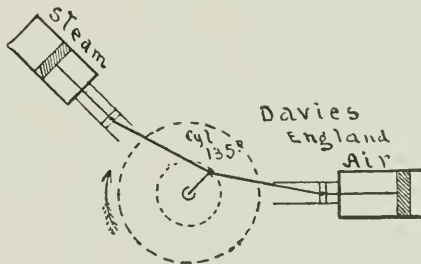


FIG. 93.—TYPE.

involved expensive construction and unsteadiness, and later experience has proved that it is expensive in construction and

does not fully equalize the compression strains. This form of construction involves much greater weight and strength in the frame, all of which has been obviated in the later construction of straight-line compressors with the controlling power in a heavy fly-wheel and moving parts.

Many efforts were made to equalize the power and resistance by constructing the air compressor on the crank-angle princi-

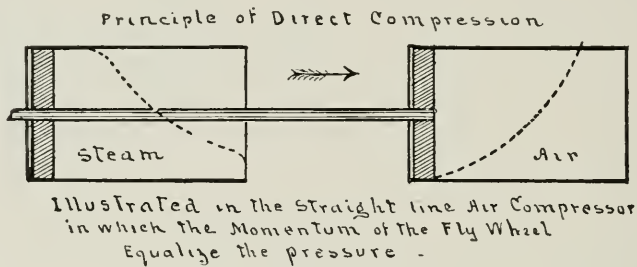


FIG. 94.—DIRECT COMPRESSION.

ple, putting the cranks at various angles, and by direct-line positions of steam and air cylinders, and this is yet in practice for compressors in ammonia refrigerating apparatus.

Fig. 94 shows the true relation of pressures when the steam and air pistons are on a direct or straight-line piston rod.

It is evident that an air compressor which has the steam cylinder and the air cylinder on a single straight rod will apply the power in the most direct manner, and will involve the simplest mechanics in the construction of its parts. It is evident, however, that this straight-line, or direct, construction results in an engine which has the greatest power at a time when there is no work to perform. At the beginning of the stroke, steam at the boiler pressure is admitted behind the piston; and as the air piston at that time is also at the initial point in the stroke, it has only free air against it. The two pistons move simultaneously, and the resistance in the air cylinder rapidly increases as the air is compressed. To get economical results it is, of course, necessary to cut off in the steam cylinder, so that at the end of the stroke, when the steam pressure is low, as indicated

by the dotted line (Fig. 94), the air pressure shall be high, as similarly indicated. The early direct-acting compressor used steam at full pressure throughout the stroke. The Westinghouse pump, applied to locomotives, is built on this principle, and those who have observed it at work have perhaps noticed that its speed of stroke is not uniform, but that it moves rapidly at the beginning, gradually reducing its speed, and seems to labor until the direction of stroke is reversed. Such construction is admitted to be wasteful, but in some cases, notably that of the Westinghouse pump, economy in steam consumption is sacrificed to lightness and economy of space.

The alternating pressures in a steam-driven compressor with a single air and steam cylinder are largely overcome in a duplex compressor, as shown by the two positions of the steam and air pistons in the upper section of the cut (Fig. 95), when moving in the same direction as shown by the direction of the two cranks at right angles on the shaft, and when the

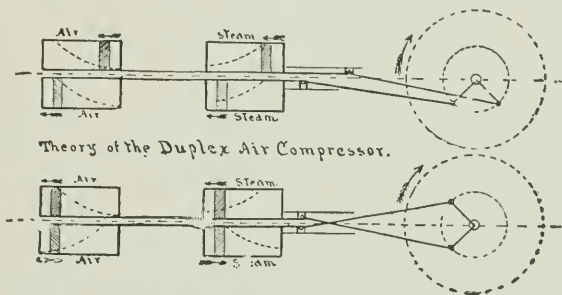


FIG. 95.—ACTION OF THE DUPLEX AIR COMPRESSOR.

pistons are moving in opposite directions as shown by the position of the cranks in the lower section of the cut.

The conditions of equalization of pressures are shown by commencing at that point of the stroke indicated in the top section. The upper right-hand steam cylinder, having steam at full pressure behind its piston, is doing work through the angle of the crank shaft upon the air in the lower left-hand cylinder. At this point of the stroke the opposite steam cylinder has a

reduced steam pressure and is doing little or no work, because the opposite air cylinder is beginning its stroke. Referring now to the lower section, it will be seen that the conditions are reversed. One crank has turned the centre, and that piston which in the upper section was doing the greatest work is now doing little or nothing, while the labor of the engine has been transferred to those cylinders which a moment before had been doing no work.

There are some advantages in the duplex construction, and some disadvantages. The crank shafts being set quartering, as is the usual construction, the engine may be run at low speed without getting on the centre. Each half being complete in itself, it is possible to detach the one when only half the capacity is required. The power and resistance being

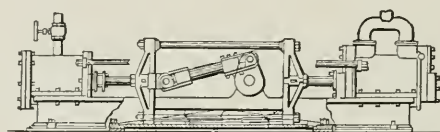


FIG. 96.—DIRECT ACTING.

equalized through opposite cylinders, large fly-wheels are not necessary. Strange to say, the American practice seems to be to attach enormous fly-wheels to duplex air compressors. It is difficult to justify this apparently useless expense in view of the facts shown in Fig. 95. A fly-wheel does not furnish power, nor does it add to the economy of an engine except in so far as it enables it to cut off early in the stroke, and to equalize the power and resistance. In other words, a fly-wheel is not a *source* of power, and in many cases it is only a means by which is accomplished equal rotative speed. It takes power to move matter, and, assuming that other conditions are equal, every engine that carries a fly-wheel that is larger than is necessary consumes a certain number of foot-pounds in turning so much metal around through space. Were it possible to cut off at the same point and rotate as positively without a fly-

wheel, it would be done away with entirely. Some straight-line air compressors are so constructed that the momentum of the piston and other moving parts is nearly sufficient to equalize the strains without a fly-wheel; but the fly-wheel is there

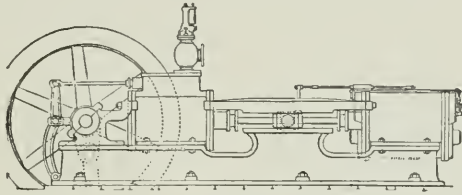


FIG. 97.—STRAIGHT LINE.

because it insures a definite length of stroke, and because it enables us to operate eccentrics and to regulate the speed of the engine uniformly.

Objections to the duplex construction are: The strains are indirect, angular, and intermittent. It is necessary therefore to largely increase the strength of parts; to add a crank shaft of larger diameter with enormous bearings, and to build expensive and very secure foundations. Should the foundations settle at any point, excessive strains will be brought upon the bearings, resulting in friction and liability to breakage. A steam engine meets with a resistance on its crank shaft that is

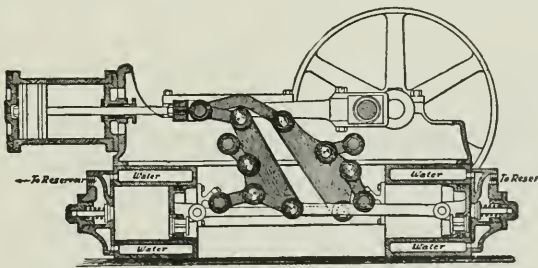


FIG. 98.—AIR-BRAKE COMPRESSOR.

comparatively uniform throughout the stroke, while an air compressor is subject to a heavy maximum strain at the end of the stroke; hence the importance of direct straight-line connection between power and resistance.

The friction loss on a duplex compressor seldom gets lower than 15 per cent, while straight-line compressors show as low a loss as 5 per cent.

To illustrate the leading types of the modern direct-acting compressors, the following sketch cuts are representative of some of the leading models:

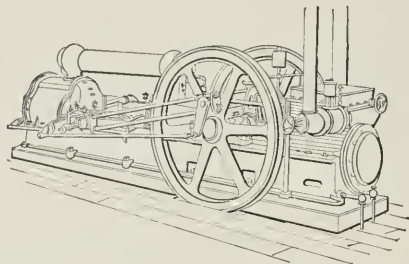


FIG. 99.—THE NORWALK.

Fig. 96 is an elevation of the Clayton air compressor with a yoke-frame connecting rod in line with the piston rods, the crank and connecting rod operating between the rods of the yoke frame.

Fig. 97 represents the outline of the "Bennett" straight-line compressor, showing a lever valve gear, operated by direct connection from the lever to the eccentric by a link.

In Fig. 98 is represented a vertical section of a unique construction in air compressors in which a double-acting steam cylinder operates two single-acting air cylinders through the medium of toggle beams, each beam having two stationary

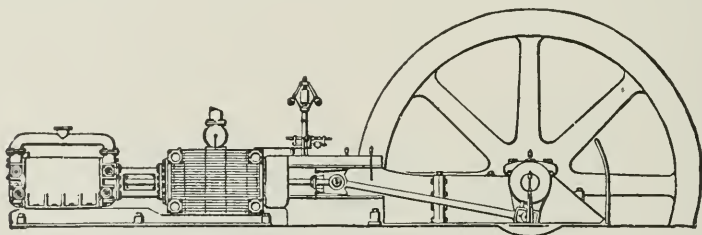


FIG. 100.—TANDEM CORLISS.

pivots and being linked to the beam for producing parallel motion of the piston rods (New York Air Brake Company model).

In Fig. 99 is given a sketch of a compound straight-line steam-actuated air compressor with an intercooler connecting the low- and high-pressure cylinders (type of the Norwalk Iron Works).

The attachment of the air cylinder tandem to a Corliss engine is one of the improvements of late years in the line of economy, and for large outputs of compressed air has no equal in operative duty.

In Fig. 100 is illustrated a vertical sketch of a single Corliss tandem-operated air compressor, and in Fig. 101 a duplex compressor of the slide-valve gear pattern in plan and elevation (the piston inlet type of the Ingersoll-Sergeant Drill Company).

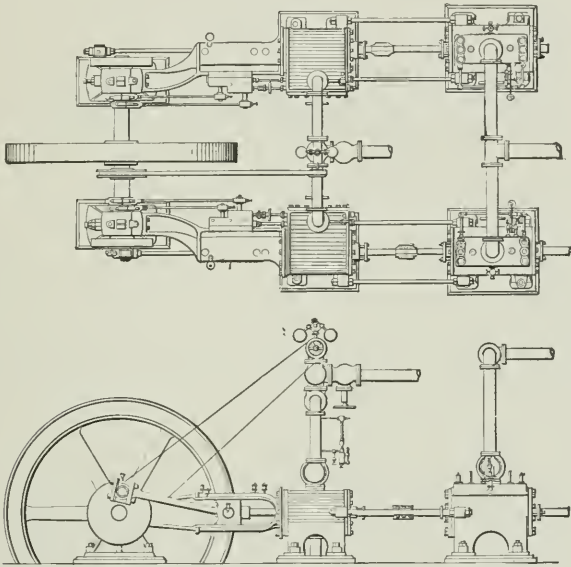


FIG. 101.—DUPLEX COMPRESSOR.

In Fig. 102 is a sketch illustration of a straight-line piston inlet compressor in vertical section and plan, as operated by a Pelton water-wheel (type of the Ingersoll-Sergeant Drill Company, which will be described in detail further on).

In Fig. 103 is represented a detailed section of the cylinders of a high-pressure air or gas compressor of the Ingersoll-Sergeant Drill Company, in which both pistons are single-acting, with water-jacketed cylinders. The forward motion of the pistons allows the air entering at the port *A* to be drawn through the annular valve in the large piston to be compressed

by the back stroke, and transmitted to the compression side of the high-pressure piston through a direct outside pipe or

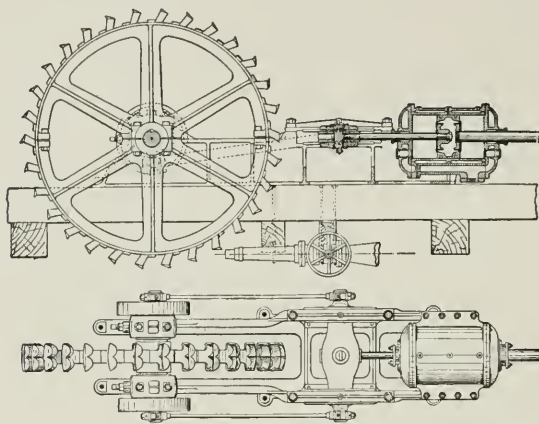


FIG. 102.—PELTON WHEEL COMPRESSOR.

through an intercooler. The lettered parts are plainly recognized and need no special explanation. The initial air cylinder is made of a size to meet the requirement of full volume to the high-pressure cylinder and to equalize the machine strains due

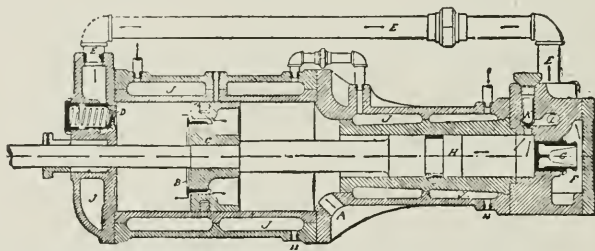


FIG. 103.—SECTION OF THE COMPOUND AIR CYLINDER.

to both half-strokes, or one revolution of the fly-wheel. The single-acting principle is conducive to efficiency in jacket cooling.

Chapter XIX.

AIR COMPRESSORS—Continued

AIR COMPRESSORS.

(Continued.)

AIR COMPRESSORS OF THE INGERSOLL-SERGEANT TYPE.

THE early compressors of the Ingersoll-Sergeant Drill Company were made with solid pistons and inlet and exit valves in the heads of the cylinders. Gradual improvements in their long experience have led to higher development in the economy of air compression. The Meyer variable cut-off and the air pressure controlling device applied to the steam cylinder, with a large reduction in the clearance of the steam cylinder, together with the straight-line effect, have brought the steam end of the compressor to a perfect action. Improvements in the air cylinder have kept even pace, and among them we illustrate the piston inlet air cylinder (Fig. 105), and the annular valve at *G* in the cut. The air is taken in through a hollow piston rod at *E* and into the hollow piston, and delivered to the cylinder each way through an annular steel valve that opens and closes automatically by its own momentum derived from the motion of the traversing piston; requiring no springs to control its operation. It has a large area of opening with but a small throw of valve, thus quickly opening a large supply port, enabling the compressor to run at high speed without a reduction in efficiency and with safety to the moving parts. As the travel of the valve is only about one-quarter of an inch, it does not move far enough to acquire sufficient momentum to injure itself or its seat, and remains perfectly tight till worn out. It is as positive in its action and as indestructible as a piston ring. The discharge valves are of the cylindrical poppet type, sliding

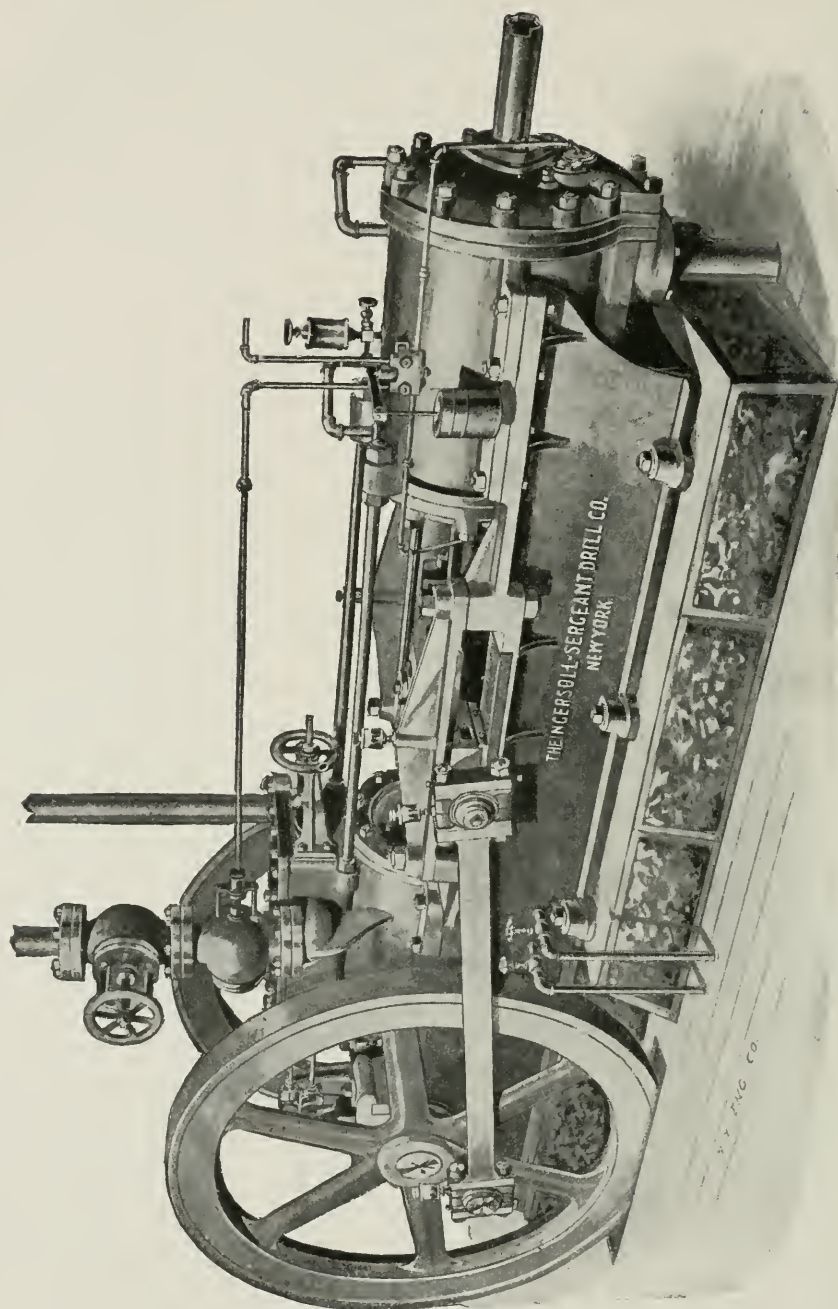


FIG. 104.—THE PISTON INLET AIR COMPRESSOR.

in screw caps with helical springs. Cylinder and heads are water-jacketed.

In Fig. 106 is illustrated a late improvement in the valve arrangement of the air cylinders of this company. The intake valves are made large and of light weight, and so protected by the overlap of the cylinder heads that they cannot be drawn into the cylinder by the breakage of a stem. The vertical movement of all the air valves insures even wear on their seats. This position of the valves enables a full water-jacketing of the heads of the cylinders.

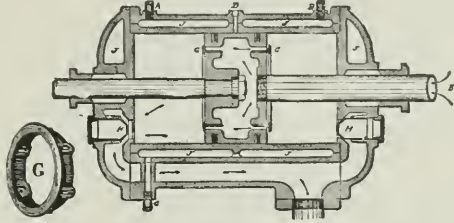


FIG. 105.—THE PISTON INLET.

In Fig. 107 is illustrated an elevation and plan of the piston-inlet belt compressor of this company, showing the swivel-block cross-head for equalizing any irregularity in setting up the connecting-rod brasses, a special feature of the transmitting gear of these compressors.

In Fig. 108 is illustrated the unloading device by which a uniform air pressure is kept in the receiver and pipe line. It is automatic, requiring no attention from the engineer further

than to set it for the required pressure. A weighted piston safety-valve is attached to the air cylinder, and connected with the air receiver, and with a discharge valve on each end of the air cylinder, also with a balanced throttle valve in the steam

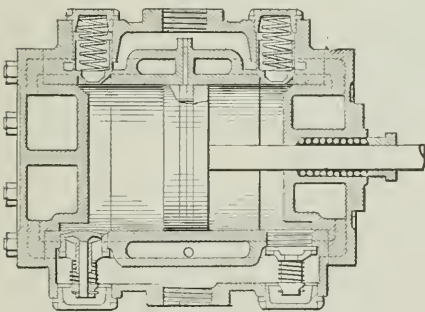


FIG. 106 —VERTICAL VALVE CYLINDER.

pipe. When the pressure of the air gets above the desired point in the receiver, the valve is lifted and the air is exhausted

from behind the discharge valves, thus letting the compressed air at full receiver pressure into the cylinder at both ends, and balancing the engine. At the same instant the compressed air is exhausted from the piston connected with the balanced steam valve and the steam is automatically throttled, so that only enough steam is admitted to keep the engine turning around, or to overcome the friction, no work being done.

When the compressor is unloaded, it is evident that the function of the air piston is merely to force the compressed air

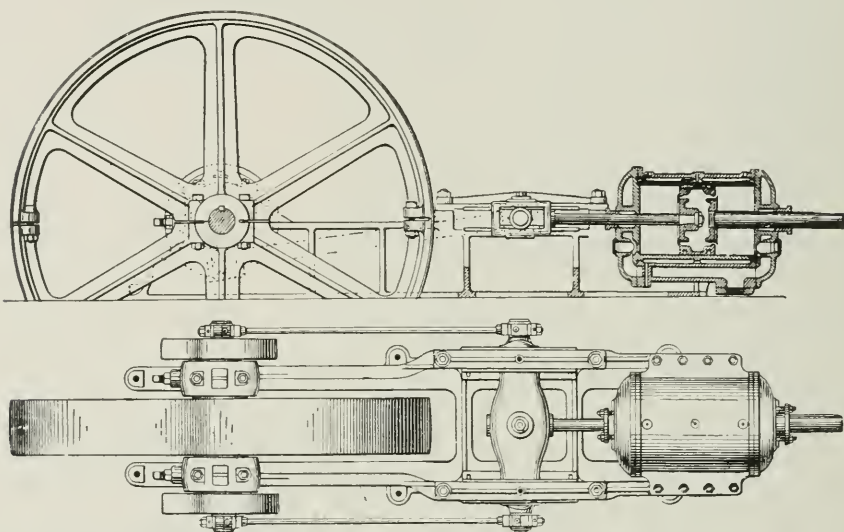


FIG. 107.—THE PISTON INLET BELT COMPRESSOR.

through the discharge valves and passages from one end to the other until more compressed air is required, this being indicated by a fall in the receiver pressure. The weighted valve now closes and the small connecting pipes are instantly filled with compressed air; the steam valve automatically opens and the compression goes on in the regular way. The unloaded indicator card (Fig. 109) shows the air-pressure conditions under the control of the unloading device by the black lines, and the normal compression by the dotted lines. Another function of this device is to prevent the compressor from stopping or

getting on the centre. Direct-acting compressors are liable to centre when doing work at slow speed.

In Fig. 110 is illustrated a pair of straight-line air compressors placed side by side as a duplex compressor, operated from a high water-head with double nozzles and Pelton wheels. The

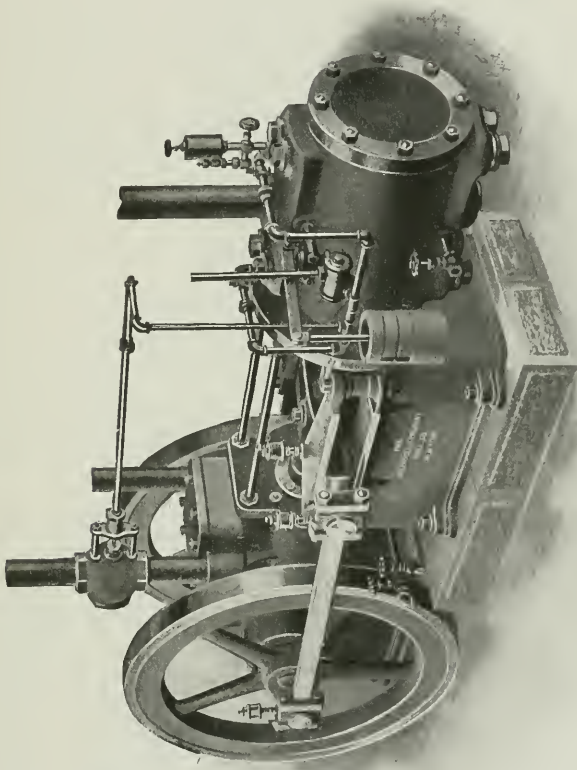


FIG. 108. THE UNLOADING DEVICE.

size of the Pelton wheels for direct action upon the air pistons is made to meet the requirement of a half speed for spouting velocity of the water at the nozzles to correspond to the required speed of the compressor. This plant was sectionalized for transport on mule-back, and operated in Peru, South America.

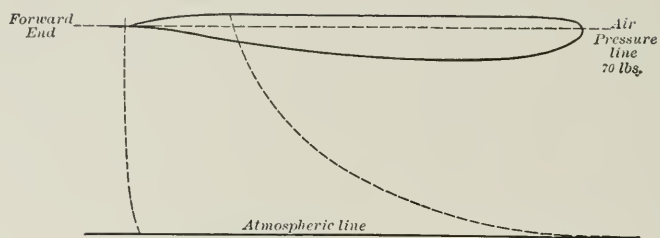


FIG. 109.—INDICATOR CARD OF THE UNLOADED AIR CYLINDER.

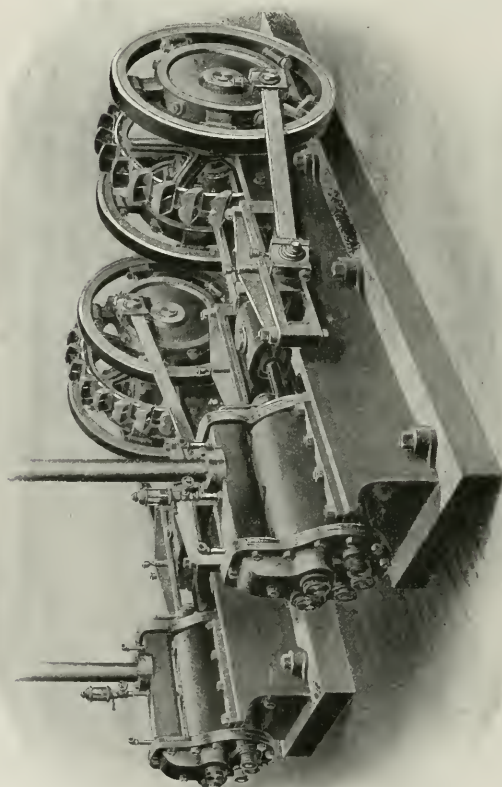


FIG. 110.—DUPLIX PELTON WHEEL COMPRESSOR.

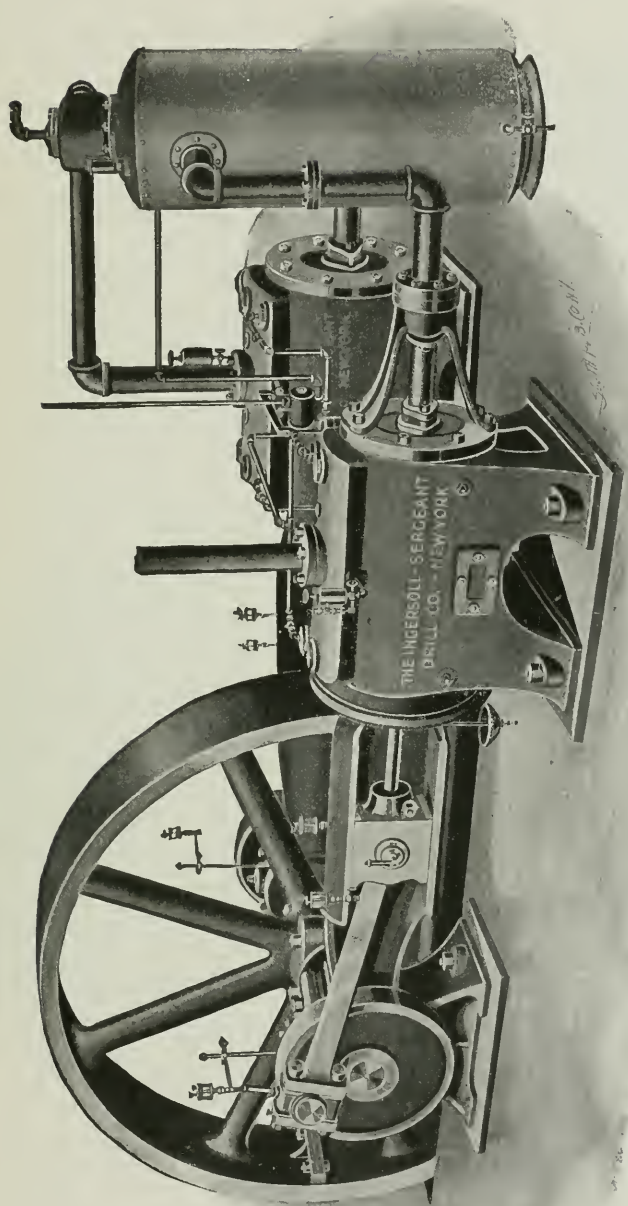


FIG. 111.—COMPOUND BELT COMPRESSOR WITH INTERCOOLER.

Piston inlet type, showing the yoke stuffing-box on the piston inlet of the high-pressure cylinder.

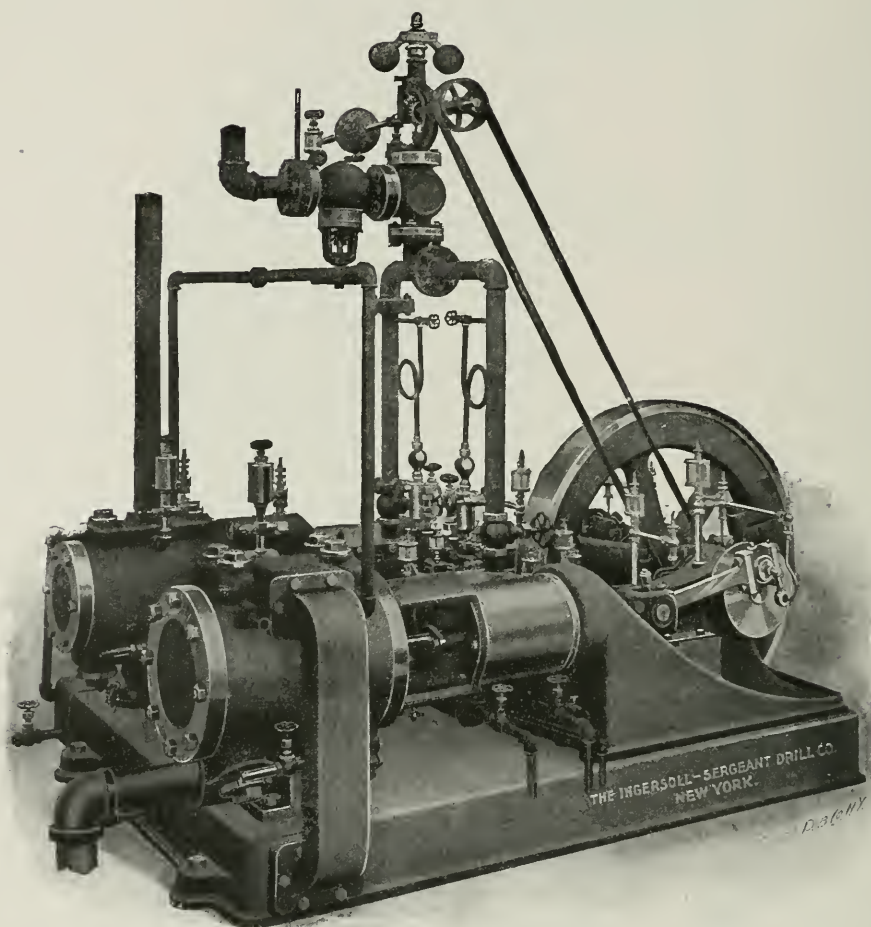


FIG. 112.—DUPLEX STEAM DRIVEN AND COMPOUND AIR CYLINDER COMPRESSOR WITH INTER-COOLER IN BASE.

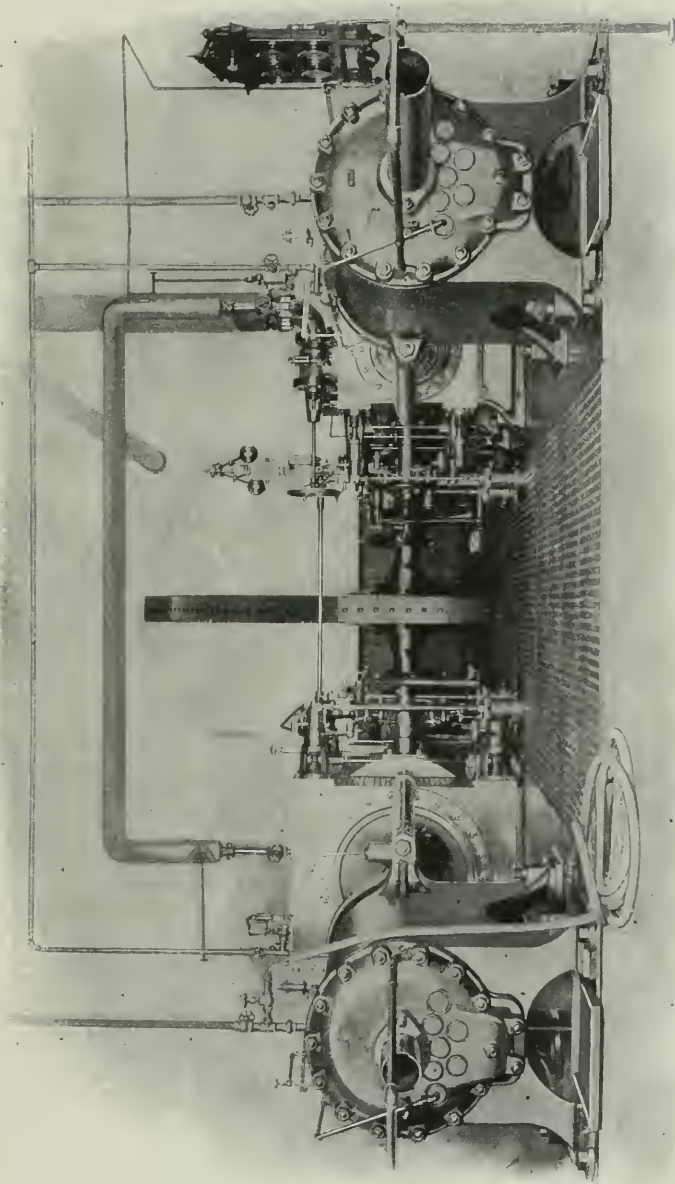


FIG. 113.- CROSS COMPOUND CONDENSING STEAM CYLINDERS WITH PISTON INLET AIR CYLINDERS.

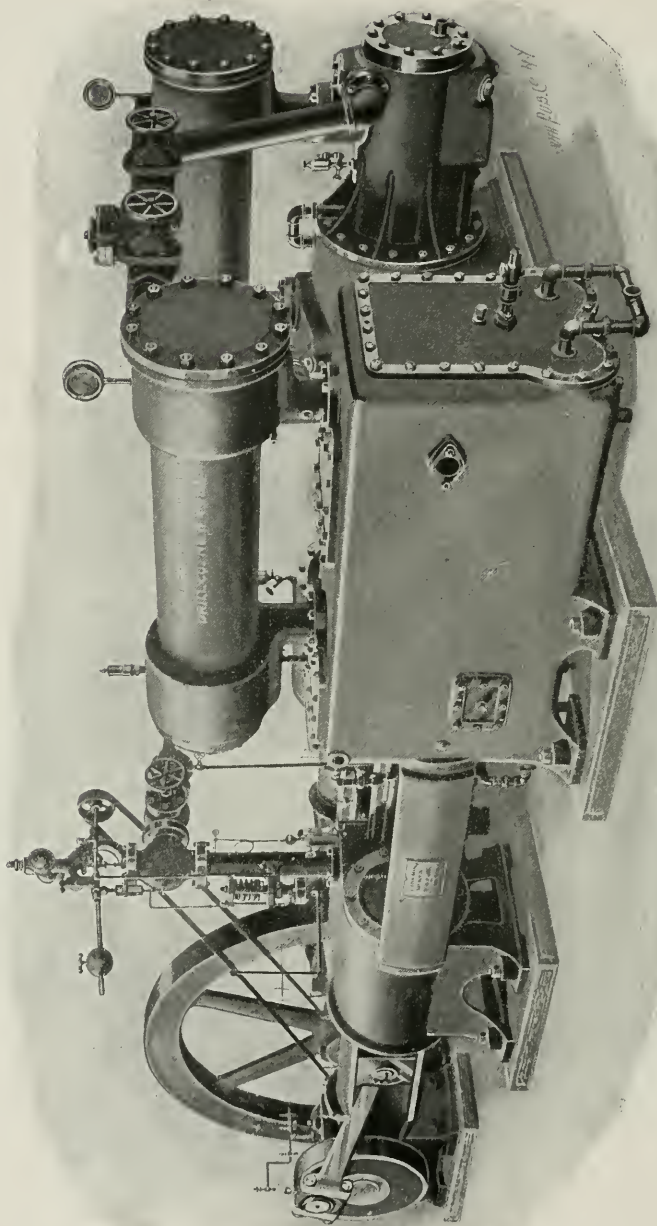


FIG. 114.—DUPLEX STEAM ACTUATED FOUR-STAGE AIR COMPRESSOR.
With intercoolers and complete water-jacketing.

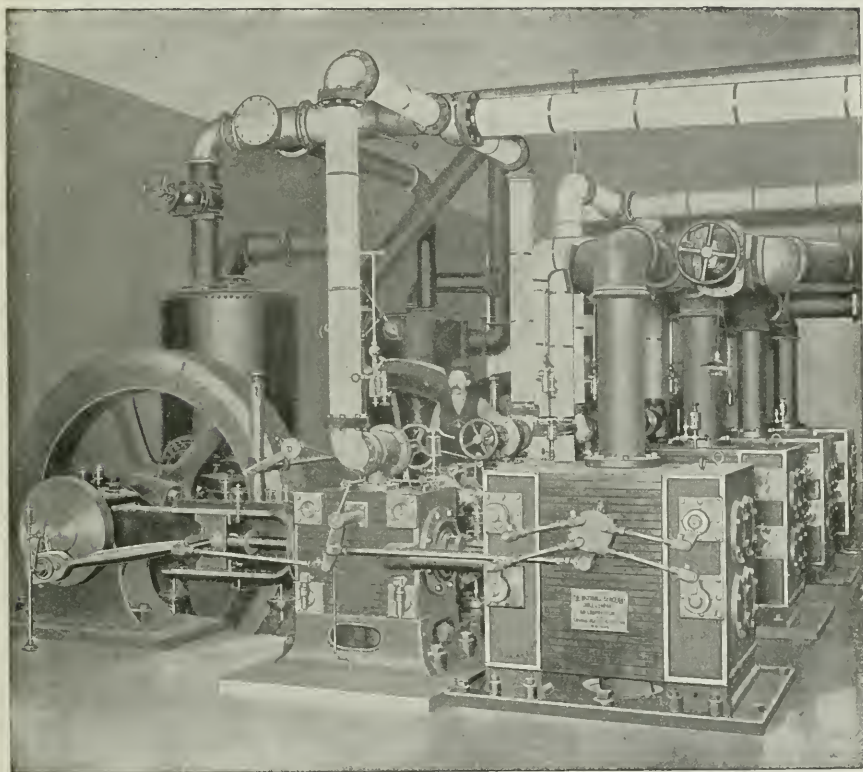


FIG. 115.- BATTERY OF DUPLEX CORLISS AIR COMPRESSORS.

Corliss type of air valves with positive motion.

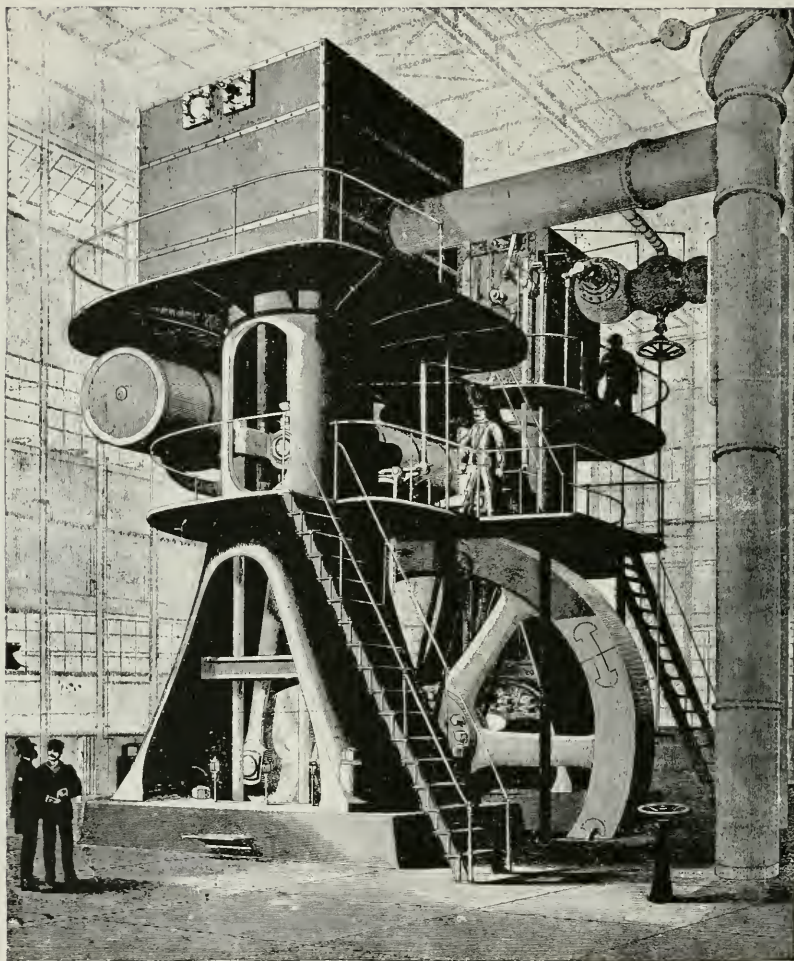


FIG. 116.—FOUR-STAGE AIR COMPRESSOR.

Twelfth Avenue and Twenty-fourth Street, New York City, Metropolitan Street Railway Company.

A THOUSAND-HORSE-POWER AIR COMPRESSOR.

The four-stage air compressor of the Ingersoll-Sergeant Drill Company that gives power to the cars of the Metropolitan Street Railway Company of New York is probably the largest

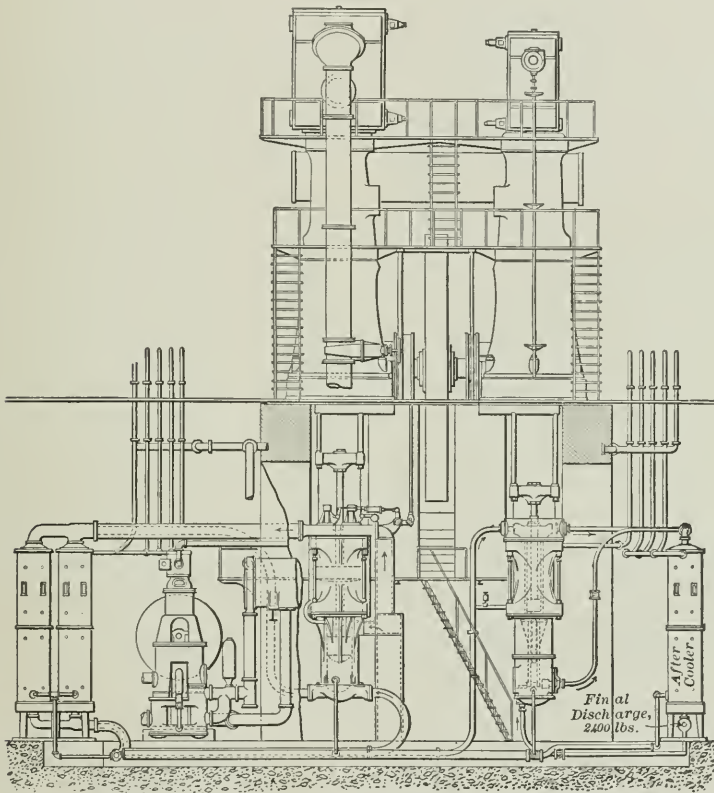


FIG. 117.—THE VERTICAL HIGH-PRESSURE FOUR-STAGE AIR COMPRESSOR.

Front view.

air compressor yet made in any country, and embodies characteristics in design and construction far in advance of ordinary practice.

The steam power of the compressor consists of a duplex vertical cross compound engine built by the E. P. Allis Company, Milwaukee, Wis., having cylinders 32 and 68 inches

diameter by 60 inches stroke, provided with Reynolds-Corliss valve gear. With steam pressure of 150 pounds and 40 revolutions per minute, it is equal to 1,000 horse power. The fly-

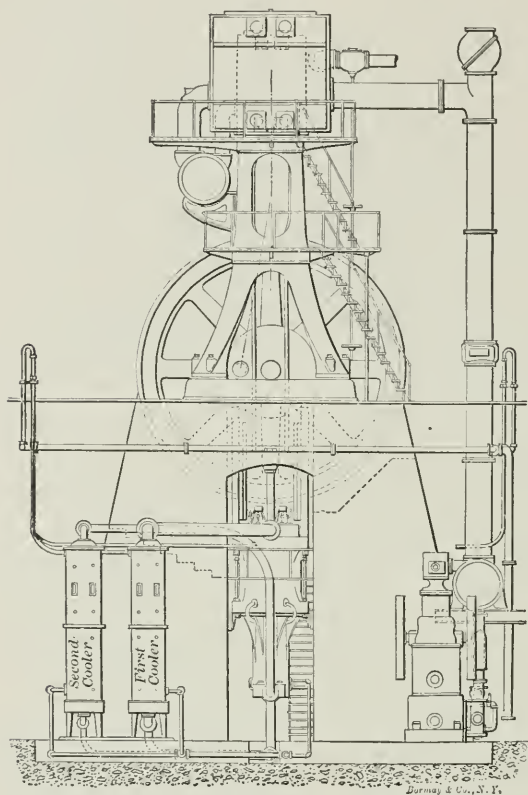


FIG. 118.—FOUR-STAGE HIGH-PRESSURE AIR COMPRESSOR.

End view.

wheel is 22 feet in diameter, and weighs 60 tons. The engine is mounted upon brick piers, and directly beneath each steam cylinder is placed a pair of air cylinders, tandem, and connected to the steam cylinder cross-heads by a yoke frame. The low-pressure air cylinder and first intermediate are 46 and 24 inches diameter placed tandem; second intermediate and high-pressure cylinders are 14 and 6 inches diameter respectively, also tan-

dem, and the stroke the same as the engine, 60 inches. All the air cylinders are single-acting.

The free-air capacity per revolution is 56.73 cubic feet; capacity at 40 revolutions 2,269 cubic feet, and the free-air capacity at 60 revolutions is 3,404 cubic feet. The approximate pressure in the first cooler is 40 pounds, the second 180 pounds, and in the third 850 pounds, the final approximate pressure in the after-cooler being 2,300 pounds.

The compressor pistons are arranged in pairs vertically in

line beneath the steam cylinders, the initial and first intermediate air cylinder being below the low-pressure steam cylinder, while the second intermediate and high-pressure air cylinders are below the high-pressure steam cylinder. Motion is transmitted from the steam-engine cross-heads through distance rods for each cross-head to a cross-head attached to the air-cylinder piston rods.

The inlet and discharge valves of the initial air cylinder are of the "Mechanical" type and of a special design. Air is admitted to the top of this cylinder through a supply pipe and leaves the cylinder through a pipe, by which it is conducted to the first intercooler.

From the cooler the air flows through a pipe to the lower end of the first intermediate air cylinder, from which it passes through a pipe to the second intercooler. From here it passes through a pipe to the upper end of the second intermediate cylinder, from which it passes to the third cooler, and from here through a pipe to the lower end of the high-pressure cylinder, and from this

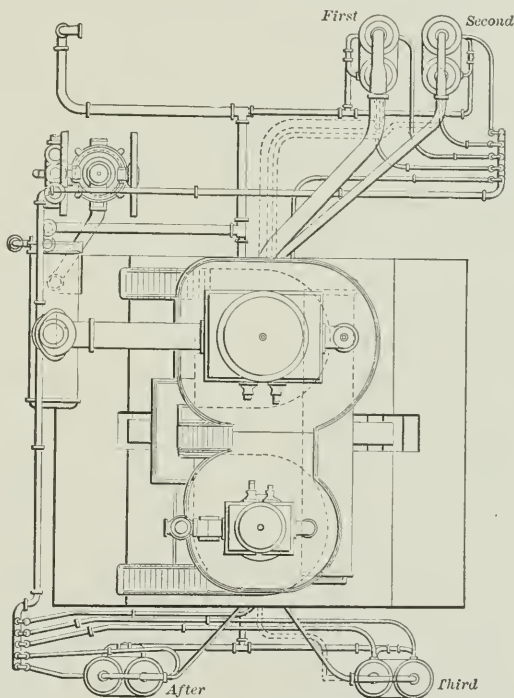


FIG. 119. —PLAN, FOUR-STAGE HIGH-PRESSURE AIR COMPRESSOR.

through a pipe to the final aftercooler, from which it is led through the outlet to the storage bottles. From this it will be seen that the air passes through the upper end of the low-pressure cylinder, lower end of the first intermediate cylinder,

upper end of the second intermediate cylinder, and lower end of the high-pressure cylinder, and in its passage between each travels through one or the other of the coolers.

The intercoolers employed are of two different designs. The two coolers for the lower pressures consist of a shell enclosing a nest of vertically arranged cooling pipes through which the air passes going from one cylinder to the other; the coolers for the higher pressures consist of a shell enclosing a pipe coil, the air passing through the coil from one cylinder to the other. In providing a cooler for the lower pressures, where great cooling surface is required on account of the large volume of air to be cooled, it was considered proper to provide tubes, but in dealing with the cooler for the higher pressures, coils were substituted so as to dispense with as many joints as possible. The coolers are arranged so that in case of a leakage of air from the cooling pipes into the shell or casing, this air rises with the circulating water up to the operating floor of the engine room and is discharged through a sight discharge pipe under the immediate care of the engineer. All the piping from the first air cylinder and through the entire compressing plant is made of copper.

What may be called an auxiliary governor controlled by air pressure is provided to act upon the governor of the steam engine. This consists of a weighted lever which is operated upon by a small piston, which in turn is actuated by the air pressure. If for any reason the pressure should become excessive the lever is lifted, when it opens a valve admitting air to a device on the governor so designed as to reduce the steam supply, and to all practical purposes throttles the engine.

Compressed air for the purpose of storage and traction by the high-pressure system consists in reservoir capacity due to a collection of steel bottles, connected together in series or by manifolds, whereby the different sections of storage can be cut out from one another.

In the storage system erected at the Twenty-fourth Street,

New York City, compressor station there are about 600 bottles. These bottles are all tested to a pressure of 4,500 pounds per square inch, and are used to store air at a pressure of 2,500 pounds per square inch. There is no wear and tear on these storage bottles other than can be made good by painting from time to time. The storage bottles are connected together with proper pipes and valves, and communicate with several charging stands in the car house. The cars can be charged with compressed air at 2,500 pounds pressure in about two or three minutes' time.

The Mannesmann bottles are all tested to a pressure of 4,500 pounds per square inch, and as they are filled with air at a pressure of 2,500 pounds per square inch, there is a factor of safety of about 2. The question is frequently put as to the liability for these tubes to explode. When the tubes are filled with the air at 2,500 pounds per square inch there is no practicable way whereby the pressure can be increased; in fact, the only thing that can happen is for the pressure to decrease.

The recent advance made in steel structural material and weldless tubes has enabled the handling of pressures with absolute safety that were not heretofore thought possible.

These high air pressures mean greater mileage of cars and vehicles, so that compressed-air power has taken a decidedly forward movement for railway and vehicle traction.

THE COMPRESSED-AIR BOTTLE OR RESERVOIR.

As there has been some misapprehension in regard to the strength of the Mannesmann air bottles or reservoirs for high-air pressures as used on street cars and vehicles, we submit some details of tests made on these tubes by the Watson-Stillman Company in presence of many witnesses. A Mannesmann steel tube 5 feet long, 8 inches diameter, and $\frac{1}{4}$ inch thick, which had been in use on a Hardie motor for about two years, carrying air pressure at 2,000 pounds per square inch, was used for the experiments.

The tube was first submitted to a hydraulic pressure of 2,150 pounds, when it was struck several blows with a 14-pound sledge having a 3-foot handle, the sledge being swung from the end of the handle, and weighing, with the handle, 16 pounds. These blows made no impression whatever. At 4,000 pounds the expansion was found to be three-thirty-seconds of an inch. When the pressure was removed, the bottle returned to its original measurement, this pressure being near its limit of elasticity.

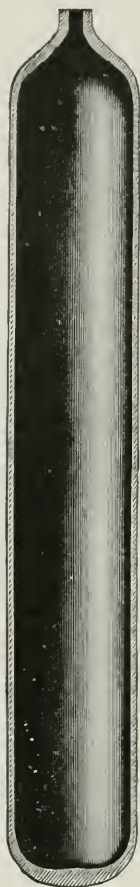


FIG. 120 —AIR BOT-
TLE.

A second application of pressure was then made up to 5,000 pounds per square inch, at which point the tube began to stretch, and between 5,000 and 6,000 pounds the tube increased one-eighth of an inch circumferentially.

At 6,100 pounds the bottle began to stretch over a small area at a point near its centre, and continued to do so until it was ruptured, at about 6,150 pounds pressure.

The character of the rupture was a mere split in the steel, 18 inches long. No pieces were detached and the fracture was quite regular in its form, showing high ductility in the material and freedom from any liability to project detached pieces in case of a rupture. As the tube tested had been in use in one of the Hardie air motors for a period of two years under a pressure of 2,000 pounds, this indicated that there had been no perceptible deterioration in use, and supported the assertion that the duration of the reservoirs may be considered as indefinite, and that no allowance in estimates of cost of operation need be made for their renewals or repairs.

Other tests have been made of the rupture of these tubes, one of which, 9 inches in diameter, expanded fifteen-sixteenths

of an inch before fracture, showing extraordinary ductility, and in all the tests made in Germany and elsewhere upon these tubes no fragments were ever detached and the fracture was always of the same character, a simple longitudinal rent usually near the middle of the tube.

It appears that the tubes did not begin to stretch until a pressure of 5,000 pounds had been reached. Consequently, 4,000 pounds, at which all the tubes are tested, is below the limit of elasticity, and 2,000 pounds, which is the maximum pressure under which the reservoirs are used in the Hardie motors, must be considered to be absolutely safe beyond the possibility of rupture, and even if a rupture should occur, there would be no danger of flying pieces or of any serious accident.

COMPRESSORS OF THE LAIDLAW-DUNN-GORDON COMPANY,
CINCINNATI, OHIO.

Fig. 121 illustrates an outline plan and elevation of the duplex slide-valve compressor of this company, of the forked-frame type, and a process print of the same is illustrated in Fig. 122. Large advantages in operation are claimed for these compressors from their straight-line action and the stability of the fork frame, which gives four bearings for a duplex compressor; the Meyer adjustable valve gear being also a leading feature in their steam economy. It is adjustable by hand, and has a range from one-fifth to four-fifths cut-off. A separate speed governor controls the general motion of the engine, and an unloading device unloads the work of the engine when excessive pressure is reached, and provides for its continuous motion until a fixed minimum pressure is reached in the air pipes, when the unloading device restores the compressor to its full work. The load relief prevents the compressor from stopping on the centre.

The cross-compound, two-stage air compressor of this company is detailed in outline in Fig. 123, showing the steam re-

ceiver and the intercooler. The Meyer adjustable cut-off is provided both on the high-pressure and the low-pressure cylinders. This compressor also has the straight-line action and the

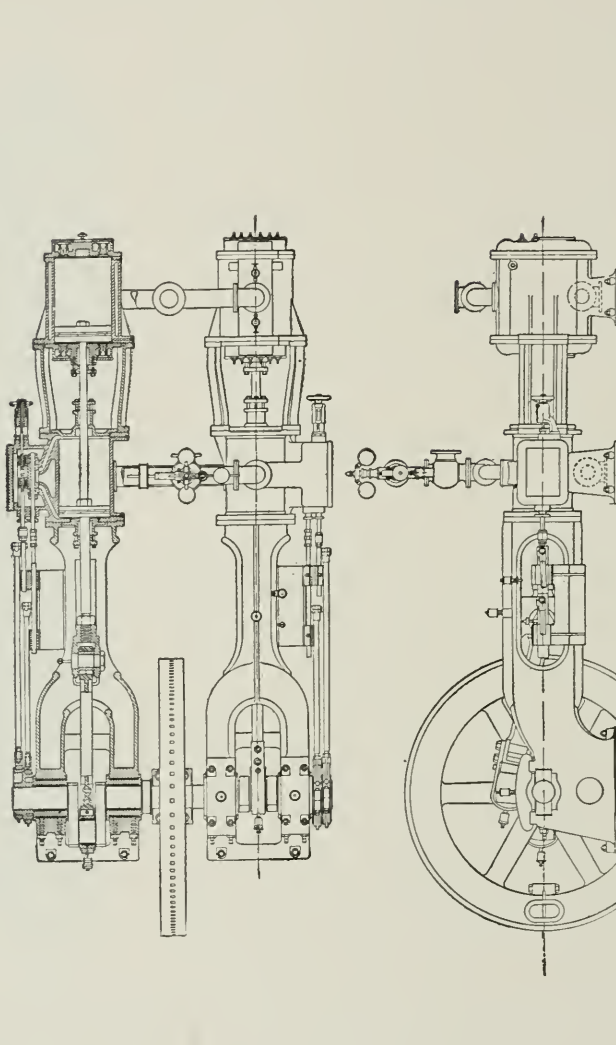


FIG. 121.—DUPLIX SLIDE VALVE AIR COMPRESSOR.
Meyer valve gear. Poppet air valves.

forked frame with centre crank for each engine. In Fig. 124 is a view of this compressor in perspective. The intercooler is directly connected to the air cylinders, and the aftercooler is placed on the air cylinders at the left. This arrangement

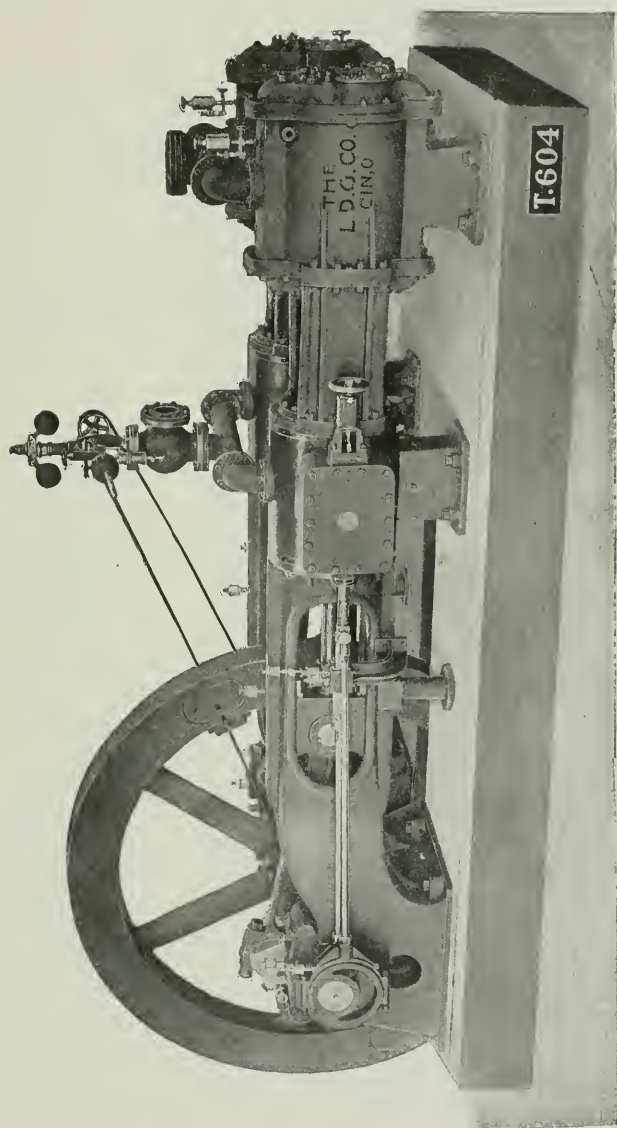


FIG. 122.—THE DUPLEX FORK-FRAME AIR COMPRESSOR.
Laidlaw-Dunn-Gordon Company, Cincinnati, Ohio.

gives dry, cool air directly to the pipe-distributing system and avoids all possibility of oil-vapor explosions. The company build about twenty sizes of single and duplex compressors for

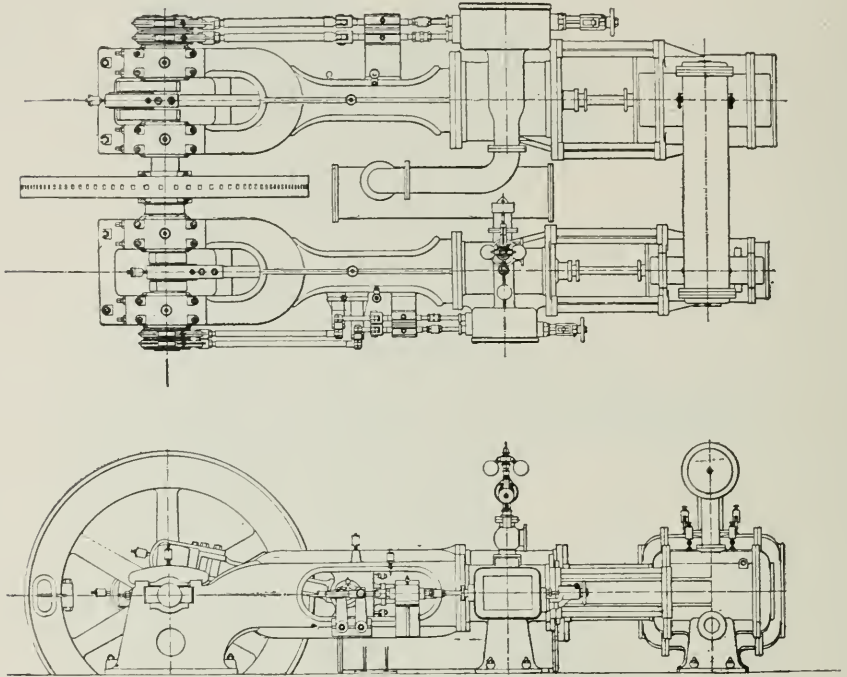


FIG. 123.—CROSS-COMPOUND, TWO-STAGE COMPRESSOR.

pressures from 35 to 3,000 pounds, and of volumes from 120 to 3,000 cubic feet per minute.

COMPRESSORS OF THE CLAYTON AIR COMPRESSOR WORKS,
HAVEMEYER BUILDING, NEW YORK CITY.

In Fig. 126 is illustrated a small post or wall compressor suitable for low pressures, up to 25 pounds, for operating pneumatic appliances or oil burners, or for testing and inflating pneumatic tires, operating small sand-blasts, and spraying. They are also furnished with a crank handle for experimental use.

In Fig 127 is illustrated a water-jacketed compressor of the

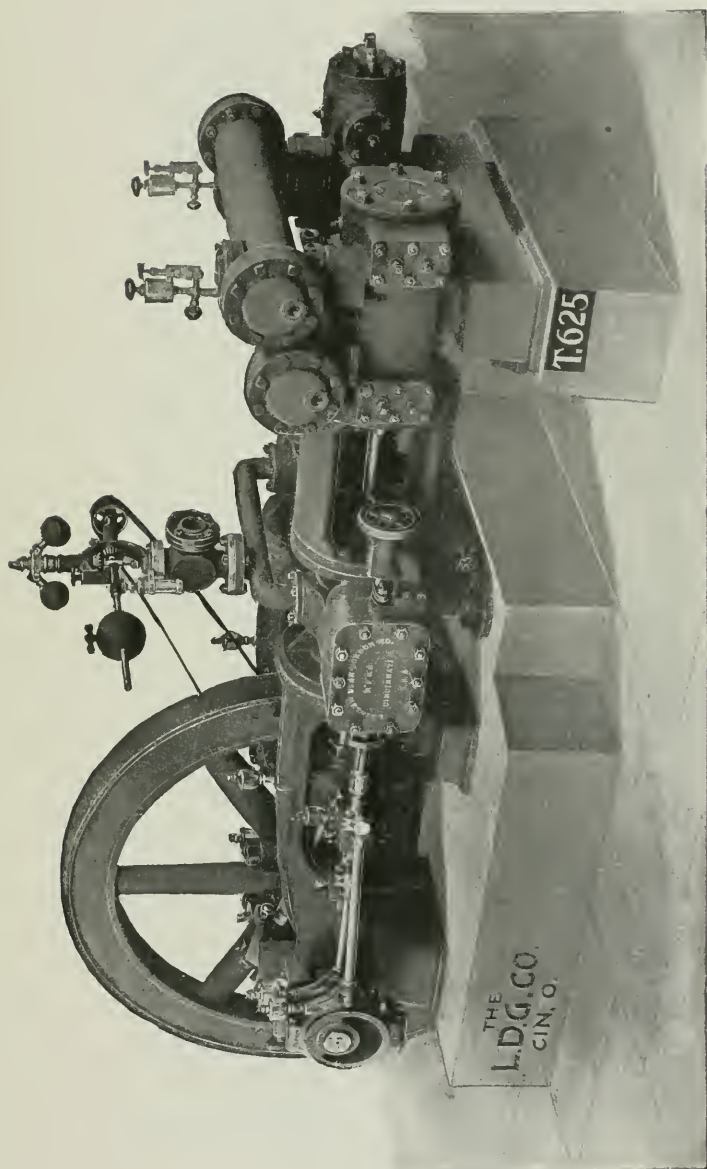


FIG. 124.—CROSS-COMPOUND TWO-STAGE AIR COMPRESSOR.
With intercooler and aftercooler.

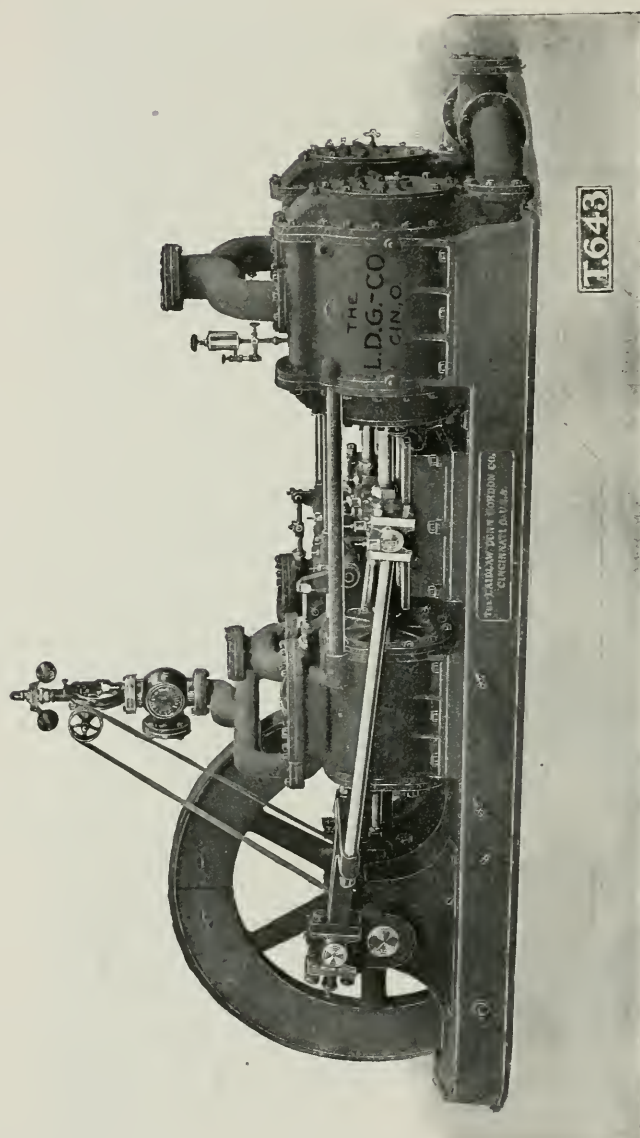


FIG. 125.—DUPLIX BED-PLATE AIR COMPRESSOR.—L. D. G. CO.
Capacities, 300 to 1,500 cubic feet free air per minute.



FIG. 126.—POST BELT COMPRESSOR.

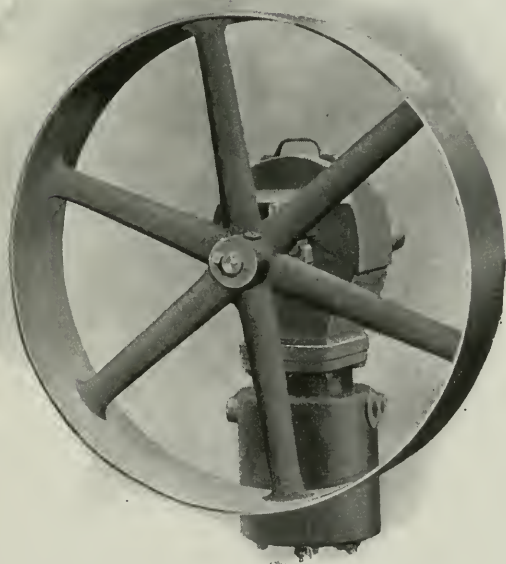


FIG. 127.—WATER-JACKETED COMPRESSOR

same type as above; designed for air pressures from 100 to 250 pounds per square inch.

Both patterns of this compressor are made of $2\frac{1}{4}$, 3, 4, 5, 6, and 7 inches diameter, by 6 inches stroke, and will compress

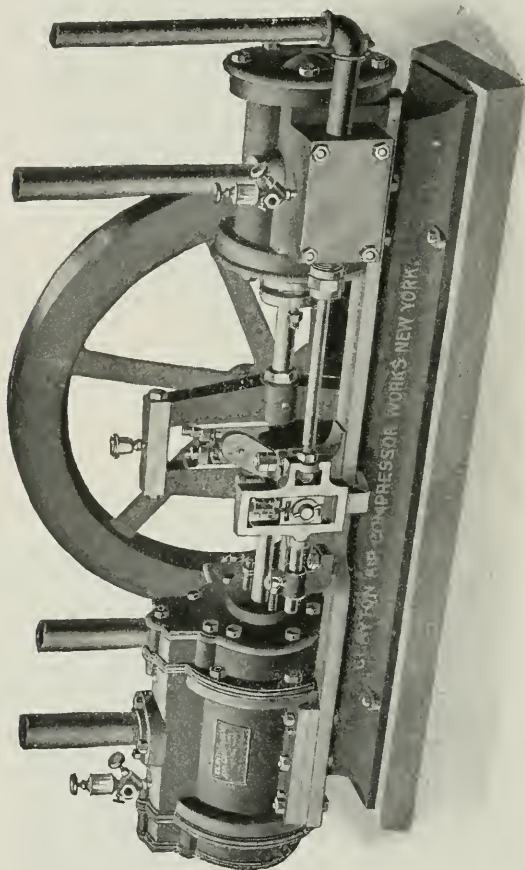


FIG. 128.—CLAYTON SINGLE AIR COMPRESSOR.

from 2 to 17 cubic feet of free air per minute up to 250 pounds per square inch according to their size and equipment.

Fig. 128 shows a steam-actuated air compressor for pressures up to 25 pounds with non-water-jacketed cylinder. They are made in sizes from 4 to 12 inches diameter of air cylinders, and with steam cylinders of suitable size for the required steam

and air pressure. At their rating they will compress 25 to 349 cubic feet of free air per minute.

In Fig. 129 is illustrated an electrically driven air compressor of the Clayton type, a most convenient method of compressing air when an electric current is available. It is made in sizes for small service.

In Fig. 130 is illustrated a duplex steam-actuated compressor of the Clayton type, which is built in sizes of equal steam and air cylinders from 4 to 10 inches in diameter and from 5- to 9-inch stroke, and at rated speed will furnish from 18 to 212

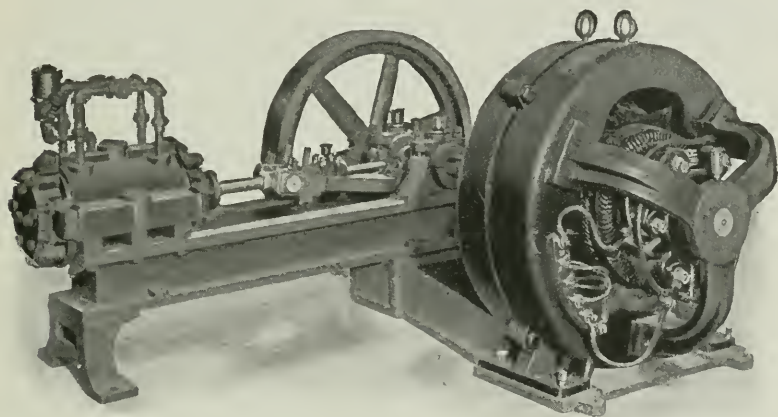


FIG. 129.—ELECTRIC-DRIVEN AIR COMPRESSOR.

cubic feet of free air per minute; they are water-jacketed and supplied with an automatic steam regulator operated by the air pressure.

The air governor (Fig. 131) is located directly upon the main discharge pipe of the compressor, with a check valve in the main line at the flanges next to the pressure gauge in the figure, to prevent loss of air when the compressor is unloaded; a throttle valve, operated by a weighted lever, is operated at over pressure by a spring-adjusted piston. The small pipe at the left-hand side of the figure is screwed through the air waste pipe and opens beneath the governor piston. Adjustment is made

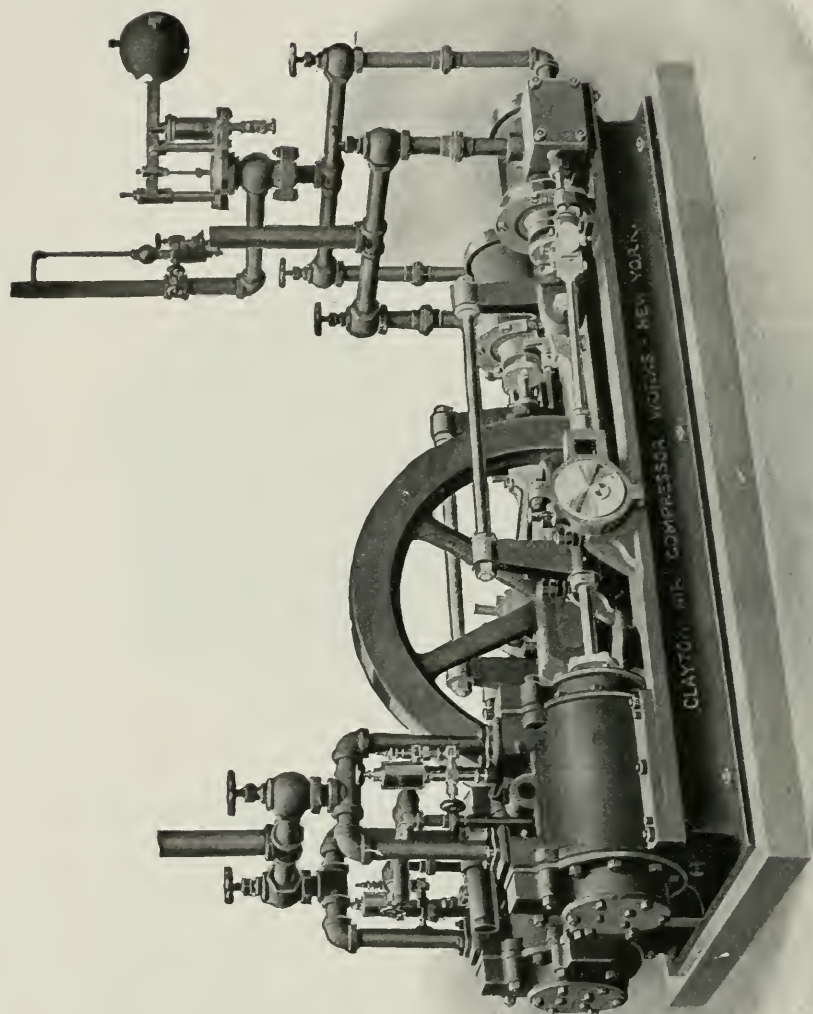


FIG. 130.—THE CLAYTON DUPLEX STEAM-ACTUATED AIR COMPRESSOR.

by the ball and a screw at the top of the piston cylinder which regulates the tension of the piston spring. It is shown in position in Fig. 132.

The three-stage compressor (Fig. 133) is of the Clayton model, and is designed for high pressure, up to 2,000 pounds

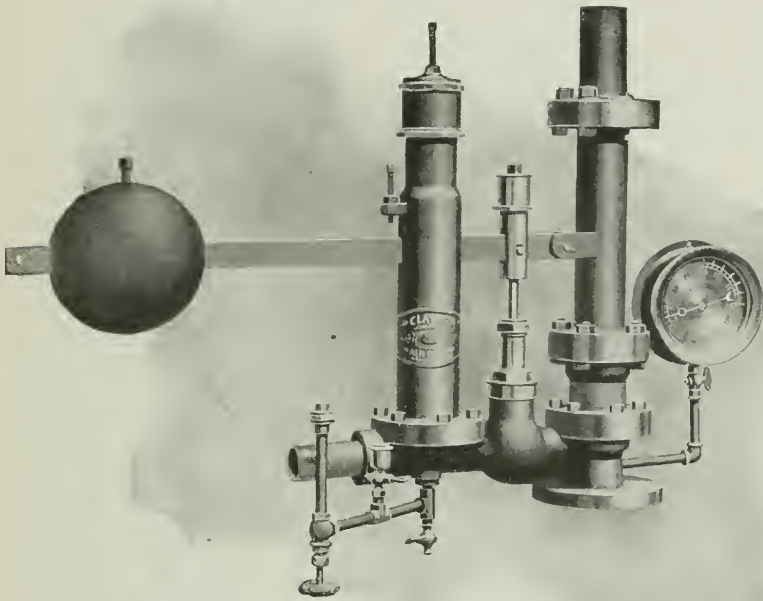


FIG. 131.—THE AIR GOVERNOR.

per square inch, and is also arranged for compressing and liquefying carbonic acid gas.

The steam cylinders are placed parallel, as in the regular pattern of duplex compressor, and the compressing cylinders are arranged in the same manner at the opposite end of the frame, and at the greatest distance from the heat of the steam cylinders. The air or gas enters the initial compressing cylinder, and, after undergoing the first compression, passes through a coil surrounded by water, and thence into the second compressing cylinder, from which it is transmitted through another

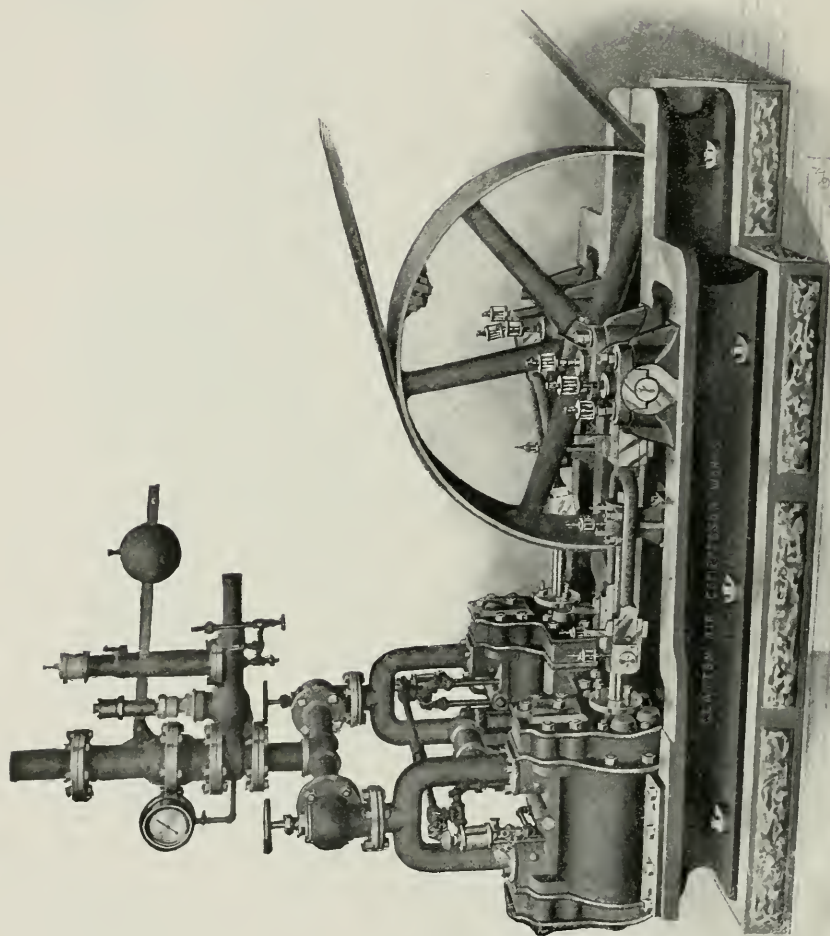


FIG. 132.—THE DUPLEX BELT AIR COMPRESSOR.

cooling coil to the third cylinder, where it undergoes the final compression. The coils for cooling the air or gas in transit between cylinders are not shown in illustration. The cranks are arranged and the cylinders proportioned to provide for an equal

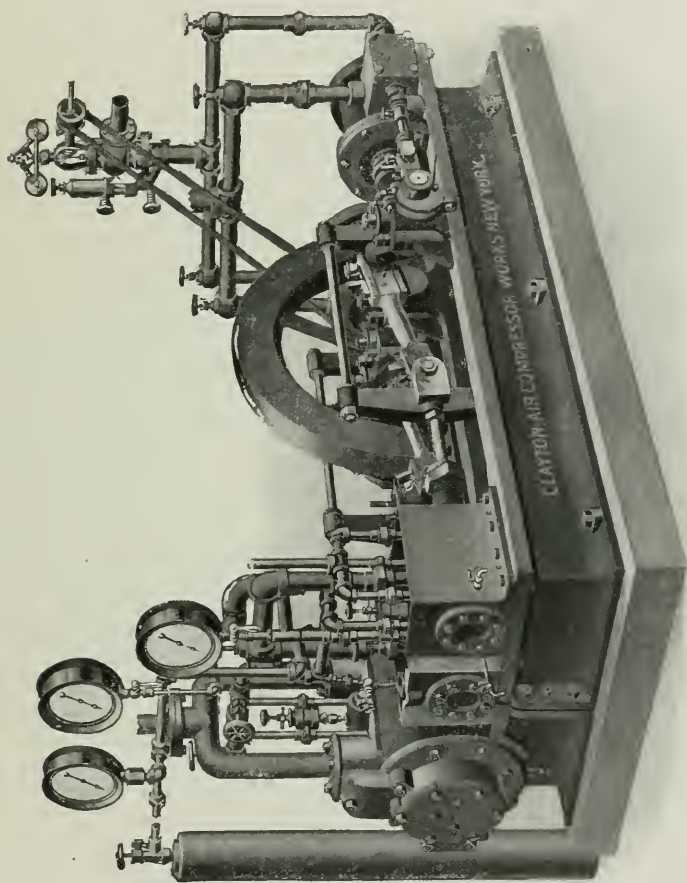


FIG. 133.—THE THREE-STAGE COMPRESSOR.

division of load, and the compressor with its steam cylinders is entirely self-contained.

The proportions of this compressor are so perfect that it secures maximum strength with minimum weight, together with a compactness and saving in floor space rarely obtained in a machine of its class. The fly-wheel is placed in the centre

avoiding all danger of injury through contact. The compressing cylinders are surrounded by water-jackets for surface cooling, and the stuffing-boxes are also cooled by a circulation of

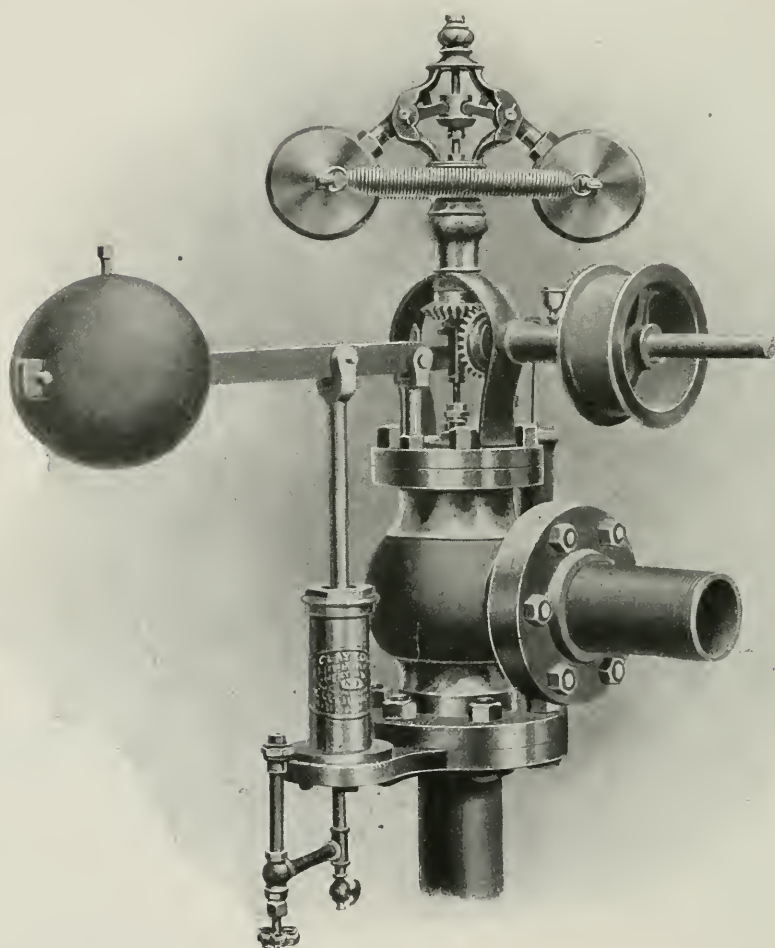


FIG. 134.—COMBINED SPEED AND AIR-PRESSURE GOVERNOR.

water. The valves, both inlet and discharge, and the pistons, are of new design and render leakage impossible. A satisfactory method of lubrication is provided without detracting from

the purity of the gas, and all the working parts are singularly easy of access. These are two of the most important features of the machine, since it is essential that all parts coming into contact with the gas be kept free from accumulation of impurities of any description, and that they be open to prompt adjustment or repair.

The Clayton combined speed and air-pressure governor (Fig. 134) supplies a much-needed want where both engine speed and air-pressure regulation are required. It is a combination of the air governor with a speed governor, and not only performs the functions of the air governor already described by limiting the operation of the compressor to the work required, but also prevents the compressor from operating at an injurious speed, should a sudden drop in the air pressure produce a greater demand upon the compressor than its highest reasonable speed will supply. Thus, should the air be used to drive rock drills or hoists, and all of them suddenly be started simultaneously, the compressor, unless provided with a speed governor, would run at an excessively high rate of speed in order to supply the unusual demand. This applies in all instances where the demand for air is intermittent. This governor is guaranteed to control both the speed of the compressor and the pressure of air with absolutely no attention from the engineer.

AIR COMPRESSORS MADE BY GUILD & GARRISON,
BROOKLYN, N. Y.

Among the large variety of air compressors, air and vacuum pumps made by Guild & Garrison, Brooklyn, New York City, we illustrate the double-acting horizontal air compressor (Fig. 135), which has found large employment in sugar refineries, chemical and fertilizer factories, oil works, and other industrial establishments for elevating acids and other liquids, blowing out filters and filter presses, aerating water, and for all purposes

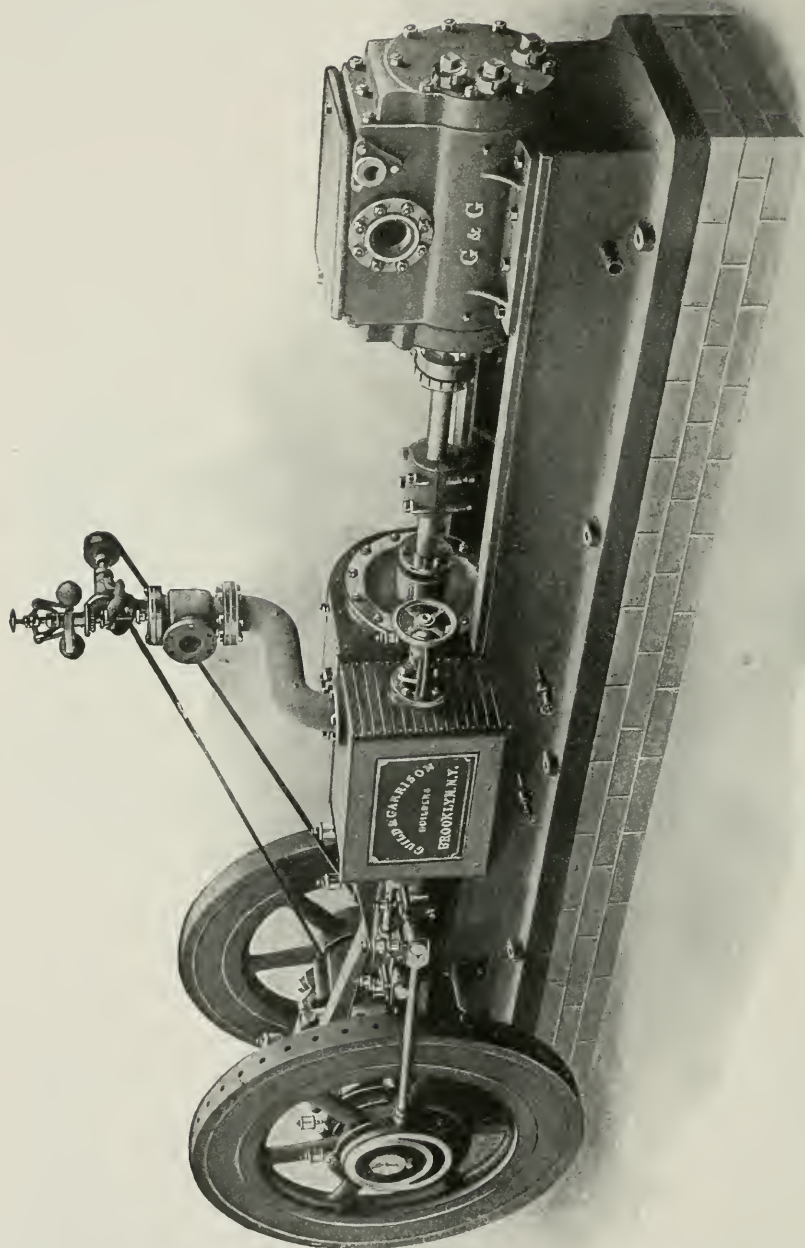


FIG. 135.—GUILD & GARRISON AIR COMPRESSOR.

in which dry compressed air is required. It is an excellent compressor for supplying air for air hammers and drills.

In their style of tandem duplex single-acting air compressor, they have designed a unique form of air valve, a section of which is given in Fig. 136. The inlet valve in the piston has a split gland guide, allowing of a ready means of removing the

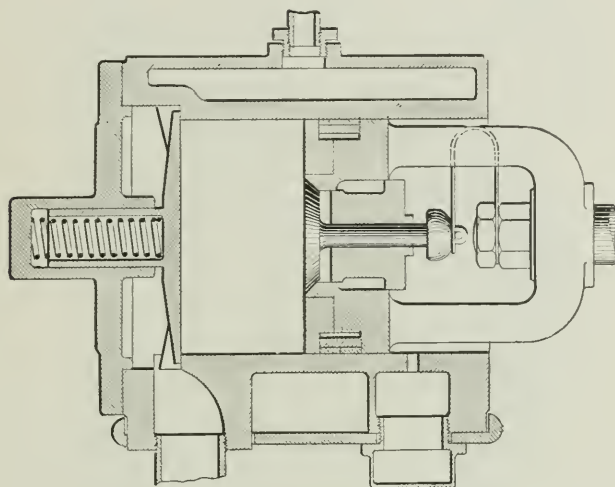


FIG. 136.—GUILD & GARRISON COMPRESSOR VALVE.

valve for repair. The discharge valve is a radical departure from the older designs of compressor valves, being a flat disc valve covering the entire area of the cylinder and held to its seat by a guide and spring. Its face and the face of the piston are perfectly flat, so that the piston may strike the valve and deliver all the air with no clearance space to detract from its efficiency. A large area of discharge is obtained by a very small movement of the valve, and no pounding is made by its action.

AIR COMPRESSORS OF THE KNOWLES STEAM PUMP WORKS,
NEW YORK CITY.

In the following pages we illustrate the various styles of air compressors made by this company, with description appended to each illustration.

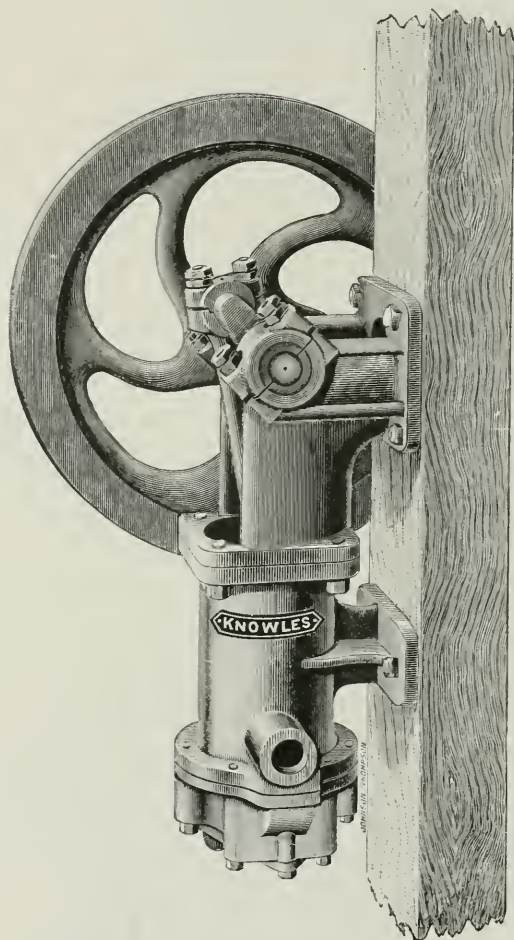


FIG. 137.—BELT WALL OR POST COMPRESSOR.

Capacity, from 2 to 17 cubic feet free air per minute, and to pressures of 100 to 150 lbs per square inch. Piston diameters, from $2\frac{1}{4}$ to 7 inch. Stroke of all sizes, 6 inch. single-acting, without water-jackets. Largely used where a limited supply of compressed air is required.

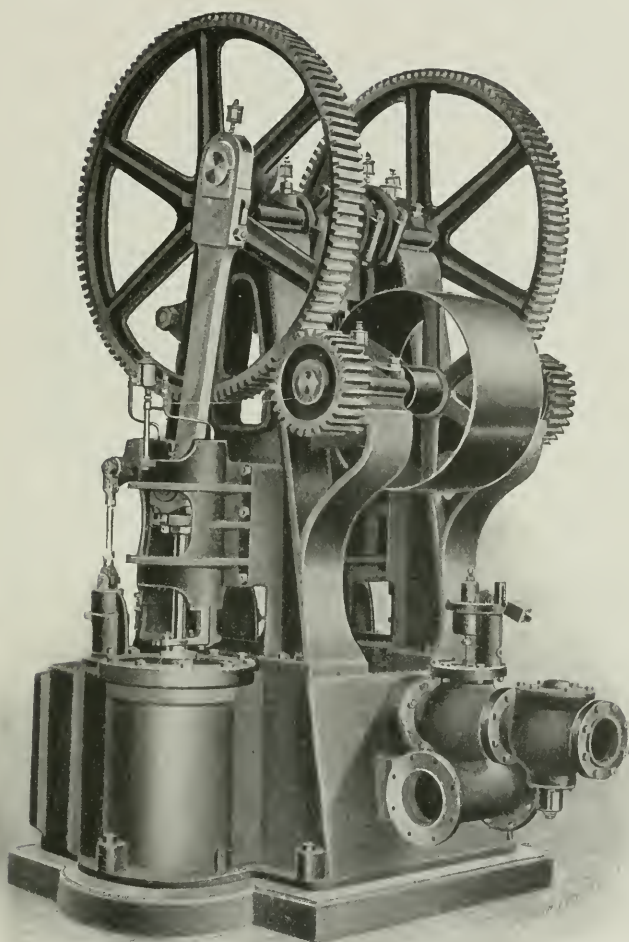


FIG. 138.—VERTICAL GEARED AND BELT AIR COMPRESSOR.

Triplex type with slide valves and unloading device by which the load is thrown off the compressor when the pressure reaches its limit in the receiver, and again put on when the pressure falls 2 or 3 pounds. A most convenient form for low pressures up to 15 pounds. Made in sizes from 480 to 3,000 cubic feet of free air per minute.

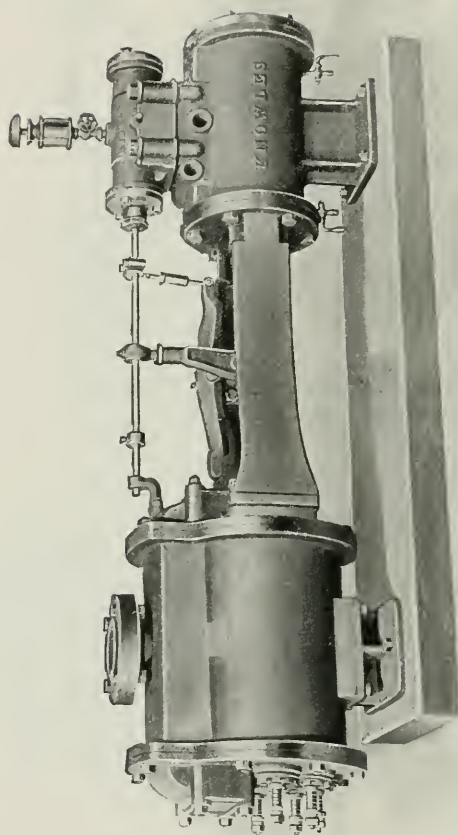


FIG. 139.—DIRECT-ACTING AIR COMPRESSOR.

Steam-actuated and suitable for from 5 to 15 lbs. pressure. Very compact and simple. Useful for agitating oils and acids, for blast and ventilating purposes, for pneumatic delivery and cash carriers. Built in sizes of from $4\frac{1}{2}$ to 48 inches diameter of cylinder, and from 5 to 48-inch stroke. Capacity, from 9 to 2,000 cubic feet of free air per minute.

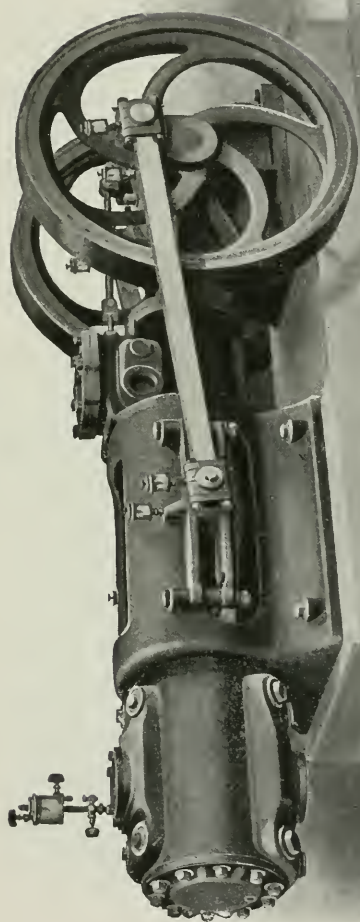


FIG 140. STEAM-ACTUATED STRAIGHT-LINE AIR COMPRESSOR.

With water-jacketed cylinder and heads. Radial valves. Air cylinders from 10 to 16 inches in diameter, and of 10 and 12-inch stroke; capacity, from 150 to 400 cubic feet of free air per minute.

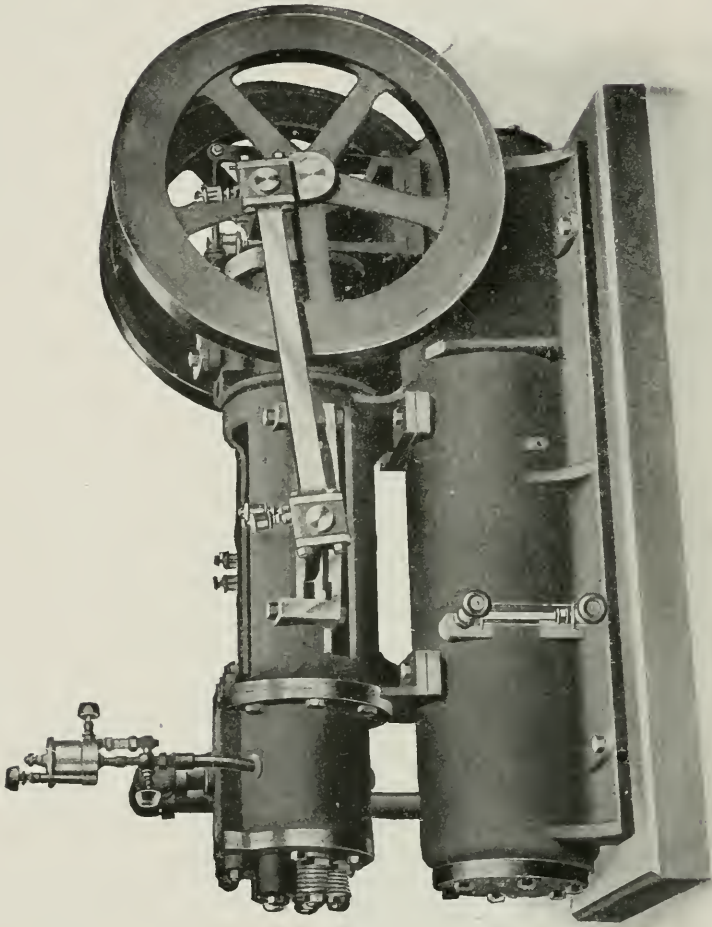


FIG. 141.—THE STEAM-ACTUATED STRAIGHT-LINE AIR COMPRESSOR.

Mounted on cast-iron receiver. A very compact arrangement that does not require a solid foundation; it runs well on a simple timber base. Made in sizes of from 5 to 8-inch diameter of cylinder, by 7-inch stroke, with capacity from 22 to 56 cubic feet of free air per minute.

—*Knaufes.*

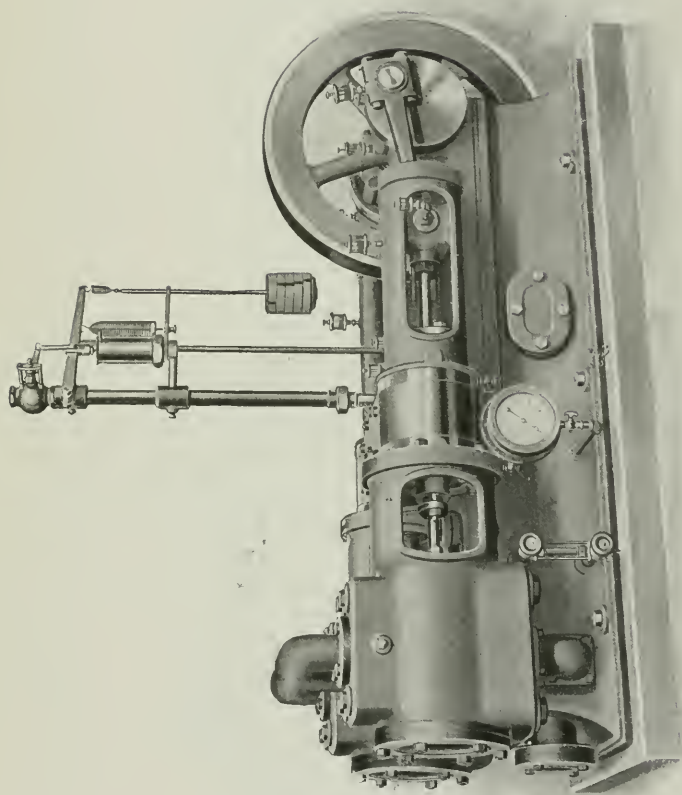


FIG. 142.—STEAM-ACTUATED DUPLEX AIR COMPRESSOR.

For 35 pounds air pressure or less, mounted on an air-receiver base. Air pressure controlled by a "Brewer's" regulator. Well adapted for compressing air for air hoists, sand blast, etc.

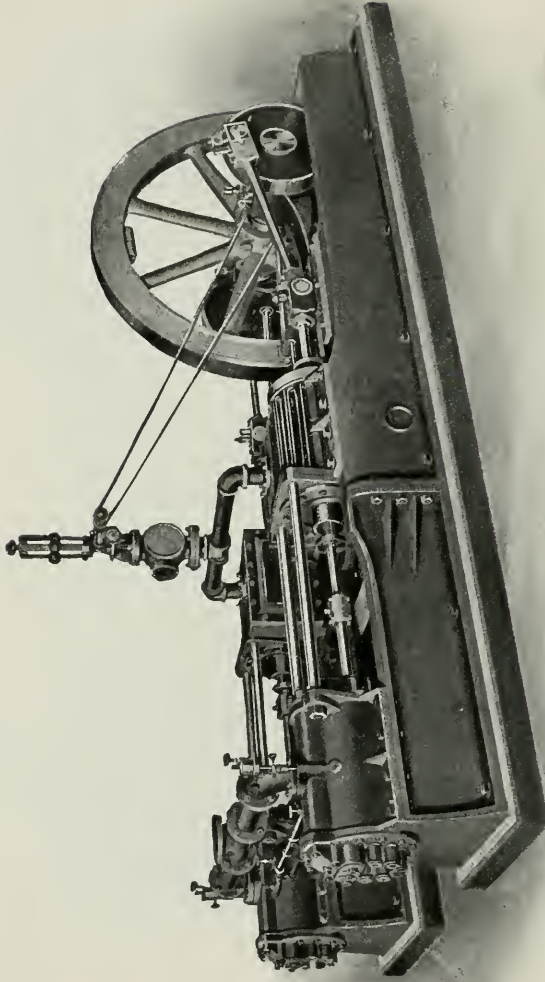


FIG. 143.—STEAM-ACTUATED DUPLEX AIR COMPRESSOR.

With strong bases tied together crosswise to make the compressor practically self-contained. Has all governing appliances. In sizes of from 14 to 24-inch air cylinders, 20 to 30-inch stroke, and capacity of from 800 to 2,300 cubic feet per minute. Suitable for shop tools, riveters, and other high-pressure air appliances.

—*Knott's.*

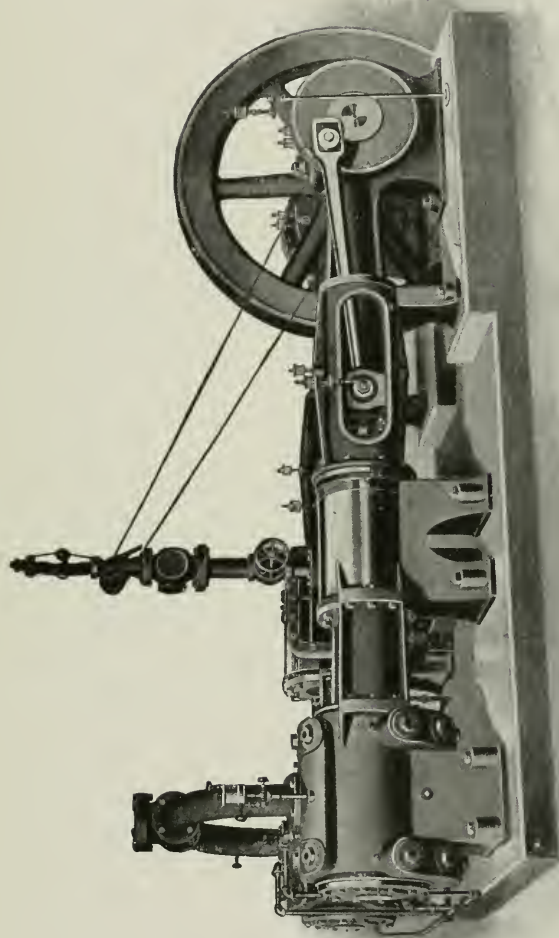


FIG. 144 — CROSS-COMPOUND DUPLEX AIR COMPRESSOR.

Non-condensing and condensing. Water-jacketed cylinders and heads. Radial valves. Meyer cut-off valve gear with steam and air regulation. Steam cylinders compound, air cylinders duplex, in sizes from 8 to 18 inches diameter, and from 12 to 24-inch stroke. Capacity, from 224 to 1,342 cubic feet of free air per minute.

Chapter XX.

AIR COMPRESSORS—Continued

AIR COMPRESSORS.

(Continued.)

AIR COMPRESSORS OF THE NORWALK IRON WORKS,
SOUTH NORWALK, CONN.

THE entire line of compressors built by this company are of the compound type, in which the heat of compression is eliminated as far as possible between the two stages of compression by the use of intercoolers in addition to the effect produced by water-jacketing the cylinders. The adoption of the Corliss type of air valves for both inlet and exit passages of the low-pressure cylinders gives a full value to the capacity of this cylinder to supply the high-pressure cylinder to its full capacity at the discharge pressure of the low-pressure cylinder.

By this system of compounding for the ordinary pressure used in rock-drilling, pneumatic tools, and the various operations in which the required air pressure may be from 50 to 100 pounds, the economy in power for operating the compressor is very apparent, and is derived not only from the heat work saved by intercooling, but also from the equalizing of the cylinder pressures throughout the stroke. This will be readily recognized from the fact that the resistance to compression in the low-pressure cylinder is derived from a longer delivery at low pressure in comparison with the action of a single compression to the full pressure.

Again, in the high-pressure cylinder the initial pressure commences with the terminal pressure of the low-pressure cylinder, and its delivery pressure is also extended over a greater part of the stroke, thus in a large measure eliminating the otherwise jerky action observed in single-cylinder air compression, and thereby lessening the momentum work of the fly-wheel (see Table XIX. for the lost work in single- and two-stage air compression).

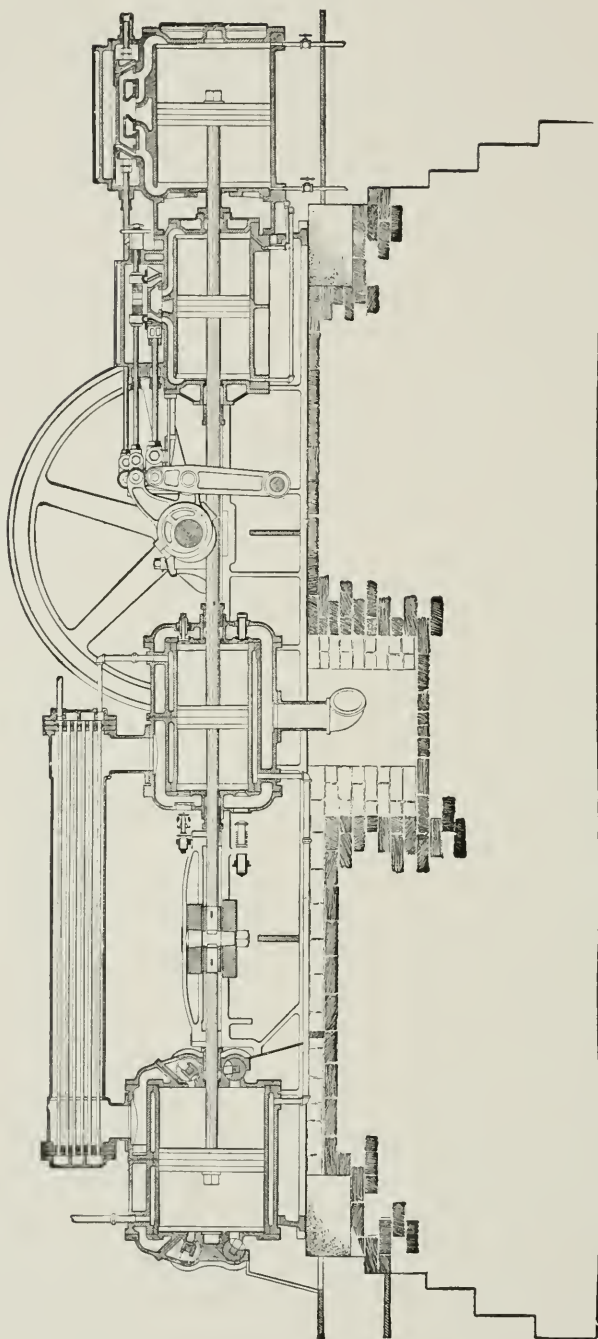


FIG. 145.—SECTIONAL ELEVATION OF DOUBLE COMPOUND AIR COMPRESSOR.

Jacketed air cylinders with intercooler. Corliss air valves on low-pressure cylinder. Meyer cut-off. Type of the Norwalk Iron Works.

Under all conditions of operation of a compound compressor the risk of cylinder and receiver explosions, from the generation of oil vapor from lubricants by the heat of compression, is entirely eliminated.

One of the great advantages derived from compound air compression and intercooling is found in the production of dry compressed air, a valuable desideratum when the compressed air is to be transmitted to a distance. Dry air prevents frosting in the transmission pipe in very cold weather, and the elimination of frost in the exhaust passages of drills and pumps is worthy of serious consideration in the choice of a compressor.

The double compound air compressor (Fig. 145) represents in a sectional elevation the leading features of construction in the designs of this company, in which are shown: the Meyer adjustable cut-off on the high-pressure cylinder; the balanced slide-valve on the low-pressure steam cylinder with rock-lever connections with the cams on the main shaft; a section of the Corliss valves on the low-pressure air cylinder, the intercooler also in section with the subdivisions in the intercooler heads; the air surface cooling tubes expanded in the sub-heads of the intercooler; the poppet valves in the high-pressure cylinder and the swivel cross-head. The outside connecting rods and details are shown in the other illustrations.

The use of water power is also made available through the operation of a turbine or Pelton wheel according to the volume or head of the water power. Fig. 146 represents a direct-connected Pelton-wheel compound air compressor, and Fig. 148 represents a geared compound air compressor to be operated by a turbine or other water-power wheel, to which a steam cylinder is attached ready for connection when water power fails.

A three-stage air compressor, with two intercoolers, is illustrated in Fig. 149. This is the standard type for charging the air receivers of mine locomotives. The steam end is fitted with adjustable steam expansion valves and speed governor.

In operation, the air is brought from some place cool and

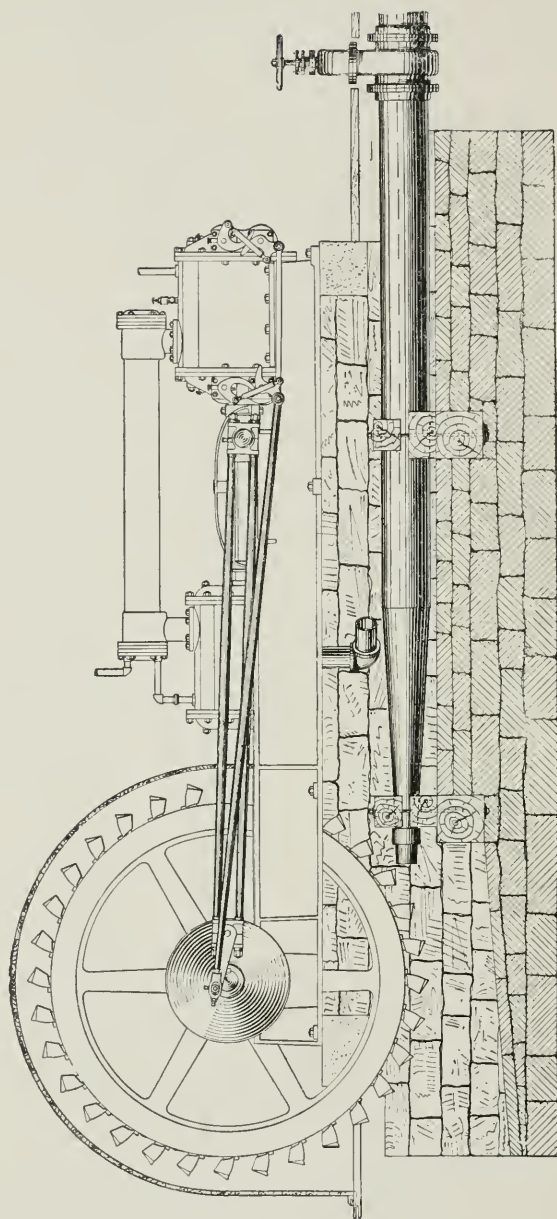


FIG. 146. COMPOUND AIR COMPRESSOR.

With water-jacketed cylinders and intercooler. Corliss valves on low-pressure cylinder. Operated by direct connection with a large Pelton wheel.

free from dust, and is admitted to the large double-acting cylinder in the centre of the machine. Here the first stage of compression is performed. The water-jacket by which this cylinder is surrounded takes away a share of the heat of com-

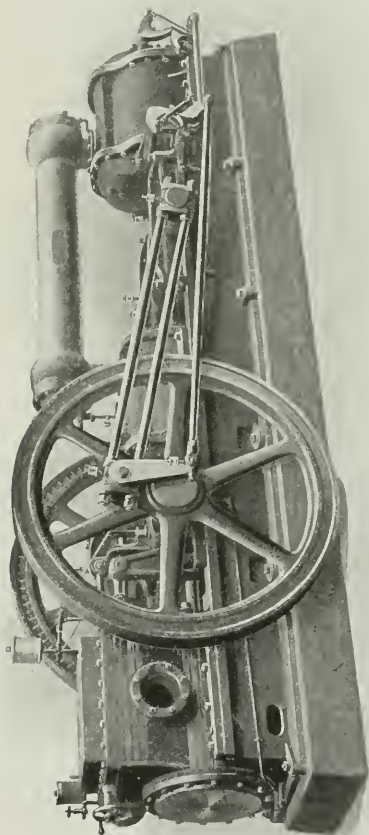


FIG. 147.—STEAM-ACTUATED COMPOUND AIR COMPRESSOR.
With intercooler and Corliss air valves on the low-pressure cylinder. Meyer cut-off on steam cylinder.

pression, after which the first intercooler extracts the remainder, bringing the air to the second cylinder at or near the temperature of the cooling water.

The second cylinder is also water-jacketed and performs another stage of the compression. From this cylinder the air

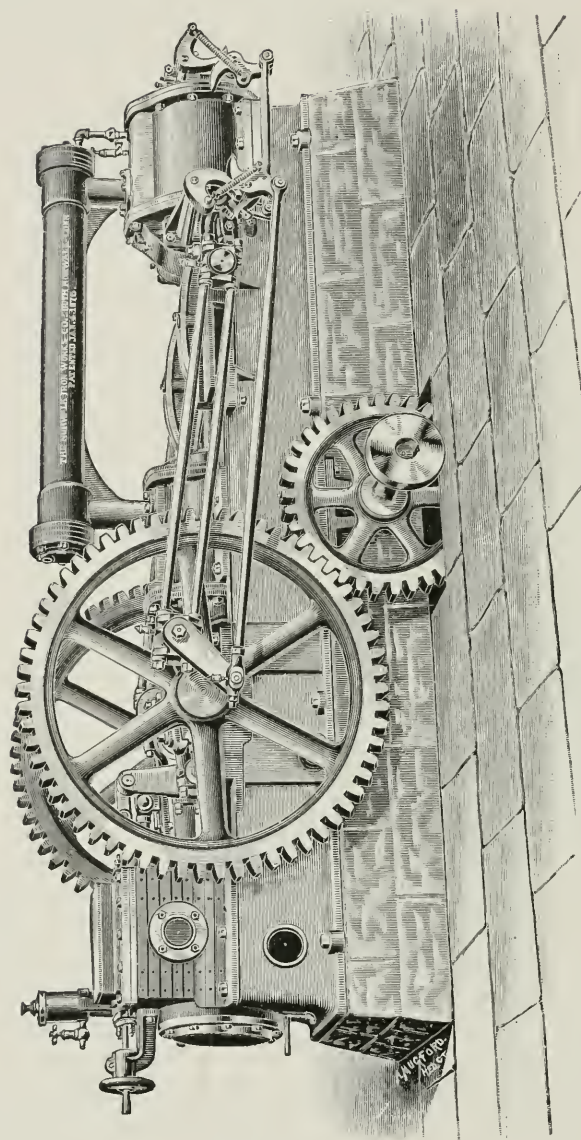


FIG. 148. COMBINATION STEAM- AND WATER-POWER COMPRESSOR.

A special construction for utilizing water power part of the year, and by simply shifting the driving pinion and connecting the steam piston, the large gear wheels become the fly-wheels and a steam-driven compressor relieves a low water power.

is led through the vertical pipe shown in front of the machine to the second intercooler, and thence into the third cylinder through the inclined pipe shown at the back. In this third cylinder, which is also jacketed, the compression is completed, and the air discharged at the connection shown at the bottom.

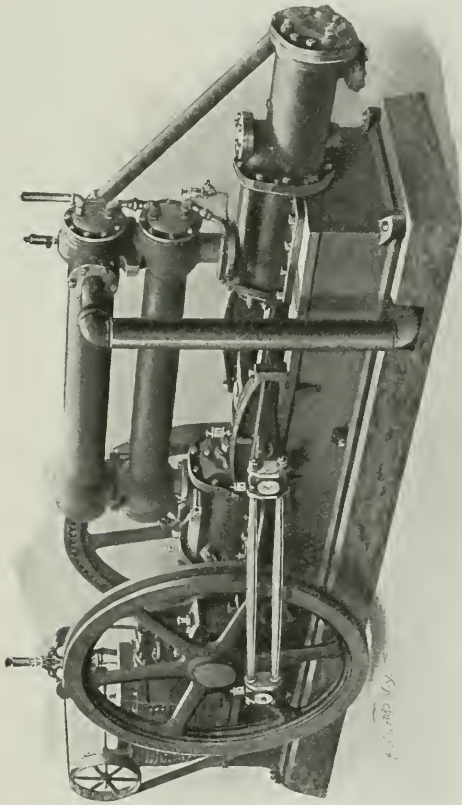


FIG. 149.—THREE-STAGE AIR COMPRESSOR.

With two intercoolers and water-jacketed cylinders. Special type of the Norwalk Iron Works for charging mine locomotives.

The pistons of the second and third cylinders are in direct line with the piston of the first cylinder and the steam piston. All the strain of compression is therefore direct push and pull on a straight steel rod.

This compressor has a pressure capacity of about 1,000 pounds per square inch.

A three-stage air compressor suitable for a still higher pressure is illustrated in Fig. 150. Other air compressors of this company are illustrated in Figs. 147, 151, 152, and 153, with the foregoing general features, with free-air capacities of from

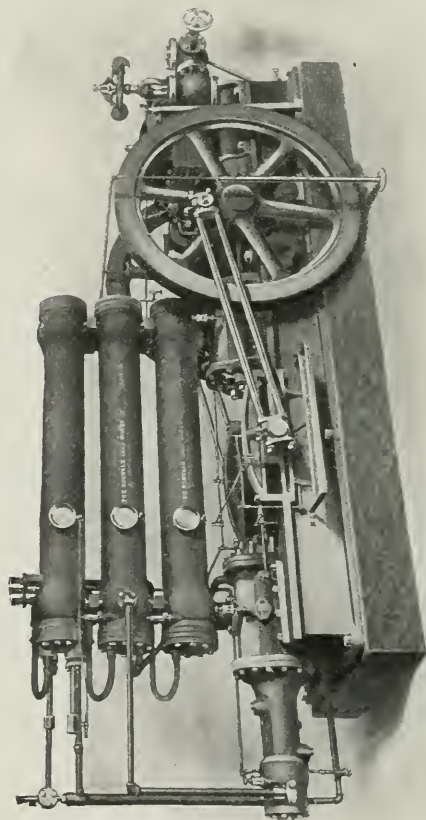


FIG. 150.—THREE-STAGE AIR COMPRESSOR.

With two intercoolers and aftercooler. For high pressures. Norwalk Iron Works.

170 to 2,350 cubic feet per minute. The sizes of the free-air cylinders vary from 10 to 32 inches in diameter and from 12 to 36-inches stroke. Diameters of high-pressure cylinders about two-thirds the diameter of the low-pressure cylinders.

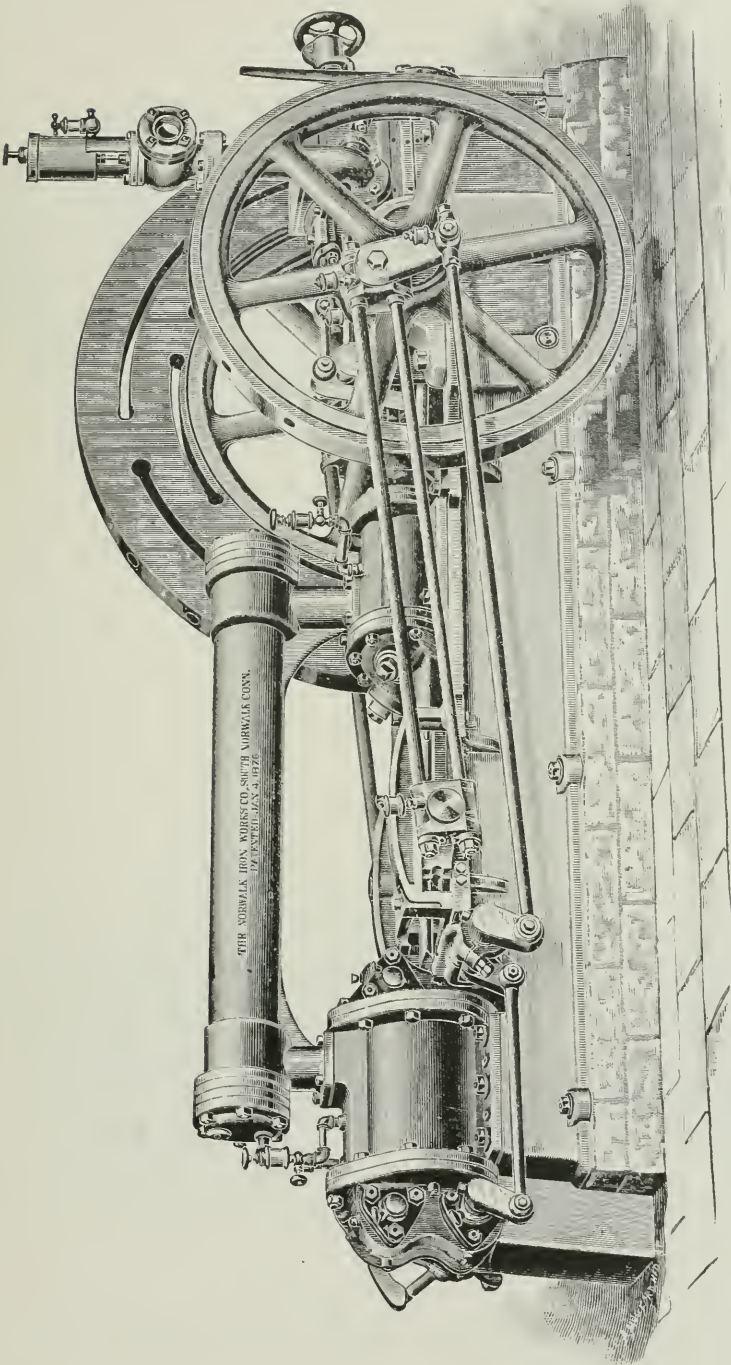


FIG. 151.—COMPOUND AIR COMPRESSOR.

Extra heavy fly wheel to insure uniformity of motion with sudden fluctuation of air pressure.

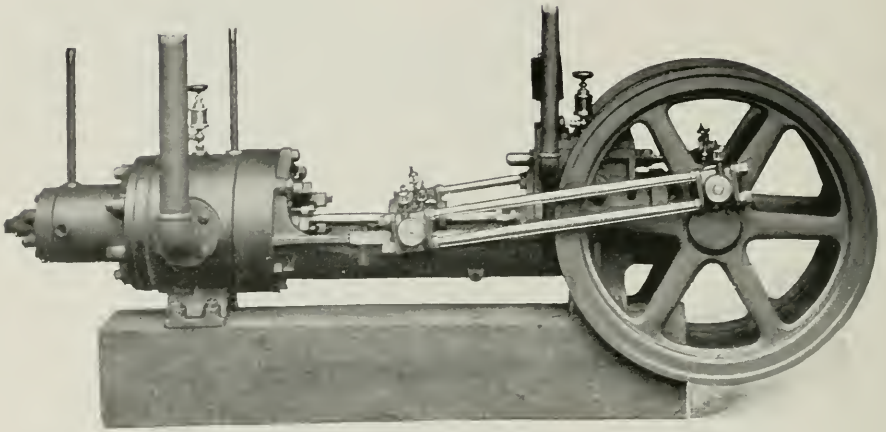


FIG. 152. —SMALL-SIZED COMPOUND AIR OR GAS COMPRESSOR.

Steam cylinder, 6 x 8 inch, with compound water-jacketed cylinders, for pressures from 150 to 500 pounds.

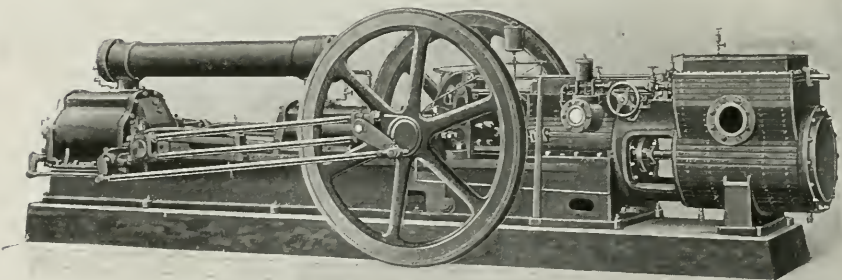


FIG. 153. —DOUBLE COMPOUND AIR COMPRESSOR.

Jacketed air cylinders and intercooler, with Corliss valves on low-pressure air cylinder. Meyer cut-off on high-pressure steam cylinder. Balanced slide valve on low-pressure steam cylinder.

AIR PRESSURE REGULATOR.

The regulator of the Norwalk Iron Works is illustrated in Fig. 154. It is placed in the line of the steam pipe near to the steam cylinder, the body being a perfectly balanced double-seated valve, controlled by the air pressure in the receiver. Above the regulating valve body is a small cylinder, having a piston connected with the balanced steam valve below by a stem as shown in the illustration. Above the small piston is a stop screw projecting above the cylinder head for regulating the lift of the piston by the compressed air pressure beneath it. The air from the receiver is led through a small safety-valve shown on the left side of the cylinder in the illustration, which regulates the pressure at which the air can enter the cylinder and close the balanced valve. Above the disc of the small safety-valve is a spring whose tension to close the valve is regulated by a screw with a milled head, allowing the spring tension on the valve to be so adjusted that the valve will lift and permit the air from the receiver to flow under the piston, and by its lift close the balanced valve. The air passes into the small cylinder beneath the piston, and if no escape were provided would drive the piston to the top of the cylinder. To regulate this action a very fine slot is cut in the side of the small cylinder. When the piston rises it uncovers this slot and thus furnishes an escape for the air which is passing the safety-valve. If only a little air passes the valve, then a small part of the slot will accommodate it and the piston will take a low position. With more air escaping, the piston will rise higher and uncover more

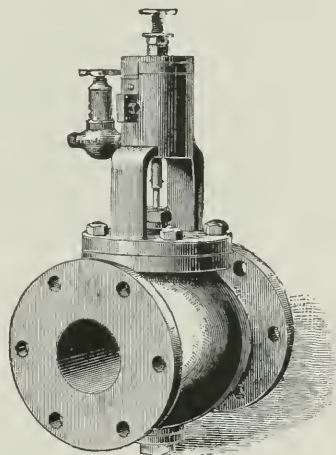


FIG. 154.—REGULATOR.

of the slot, thus providing a larger opening for its exit. As the slot is very fine, a very little difference in the quantity of air will cause the piston to assume a high or low position. After the small safety-valve begins to blow, an almost insensible increase of pressure in the reservoir will furnish enough more air to

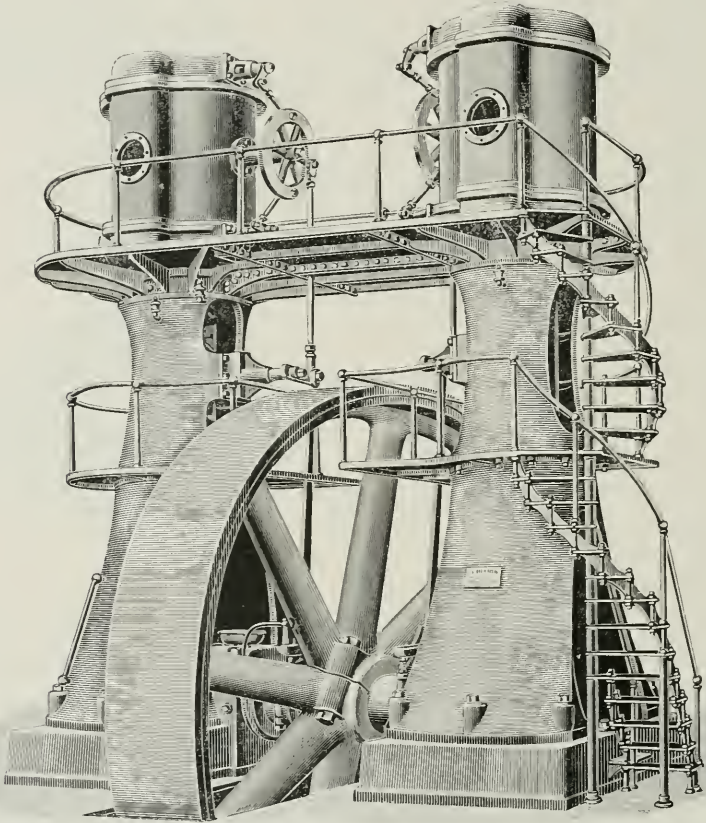


FIG. 155. VERTICAL BELTED DUPLEX AIR COMPRESSOR.

Type of the Edward P. Allis Company, Milwaukee, Wis. With Corliss air valves

carry the piston to the top of the small cylinder. Thus any degree of regulation is obtained by a very little difference of pressure. As the air which works on the piston in the small cylinder has only to perform the work of lifting the piston and valve sufficiently to uncover enough of the slot so that it can escape, its pressure is very slight. The piston is fitted loosely,

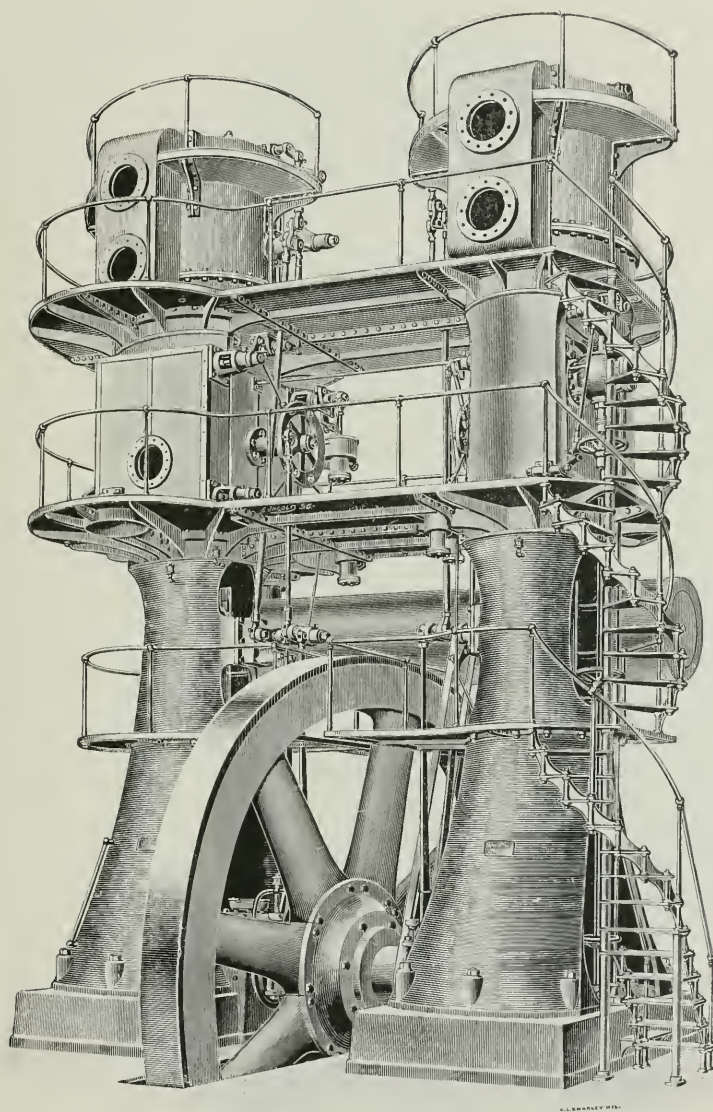


FIG. 156.—COMPOUND CORLISS ENGINE-DRIVEN BLOWING ENGINE.

Vertical type for blast furnace and bessemer work. Built by the Edward P. Allis Company, Milwaukee, Wis.

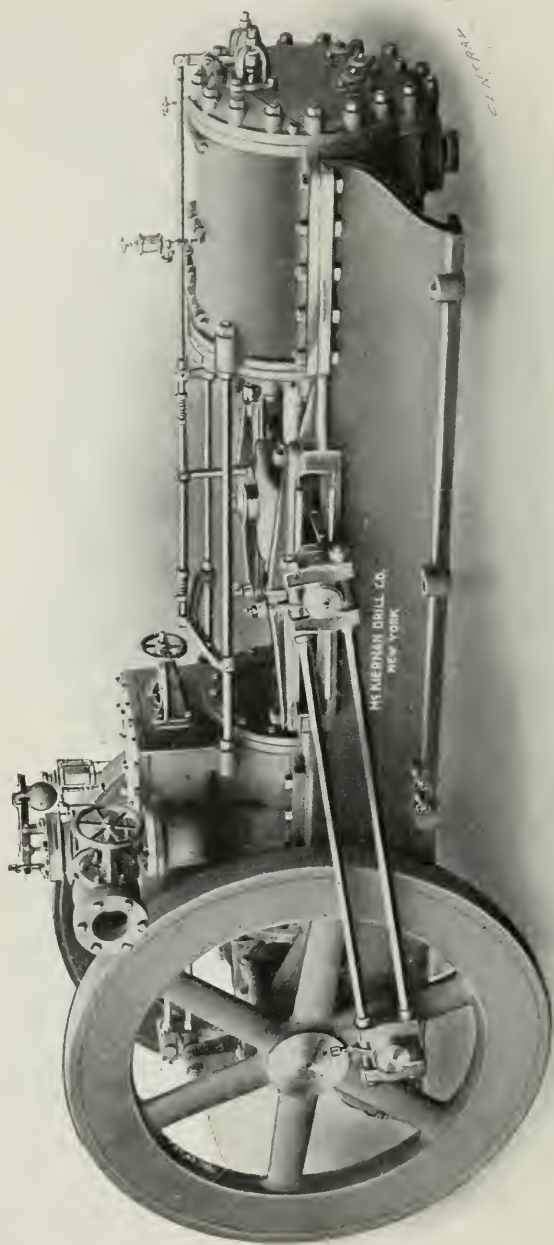


FIG. 157.—McKIERNAN STRAIGHT-LINE AIR COMPRESSOR.
With Meyer valve gear.

and the whole apparatus moves as nearly without friction as can be imagined.

When this regulator is applied to compressors having a single steam cylinder it is possible for the valve to be carried so high as to shut off all steam and stop the engine on the centre. This would be objectionable. To obviate this there is placed on the top of the small cylinder a screw stop which can be set to prevent the closing of the steam valve more than is sufficient to run the engine at the slowest speed at which it will pass the centre.

The Corliss air-valve gear of this company is somewhat peculiar; the valves are moved by cams. The shape of these cams is such that the valve remains at rest until the pressure below it is nearly equal to that above. Then the movement begins, and when the pressures are equal the valve is quickly thrown full open. In closing, the cam allows a rapid movement, so that the valve is seated before any considerable pressure comes upon it. The connection which draws

it shut is elastic, so that if the valve seat is dry no cutting can occur. This form of movement having such desirable features for heavy pressure is in a degree useful at any pressure, and has been therefore adopted for this company's standard compressors.

The Merrill compound direct-acting air compressor (Fig. 158) is one of the latest productions for the economical compression of air for pumping water by the direct displacement

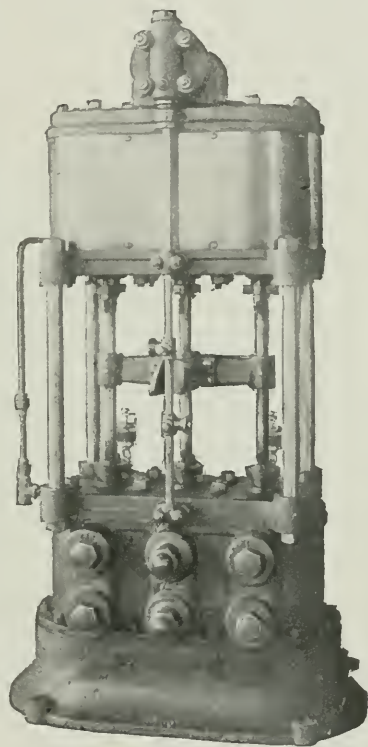


FIG. 158. — COMPOUND DIRECT-ACTING AIR COMPRESSOR.

and inductor system, and for the lesser requirement for pneumatic tools. It is an improvement upon the wasteful method of the direct-acting air-brake pump, and claims a high efficiency for a vertical direct-acting type. Its action is derived from three steam pistons and three air pistons, each pair of steam and air pistons on a piston rod, and all three pairs being connected together by a cross-head, which carries a diagonal valve gear that shifts the ports of the steam valve by rotating a ported piston, which in turn throws a spool-valve linked to a slide-valve. There are one high-pressure and two low-pressure cylinders for both steam and air. Air cylinders are water-jacketed. The central cylinders for both steam and air are high pressure; the outside are low pressure, so that each pair of steam and air cylinders is equalized as to strains. The low-pressure steam cylinders are cushioned sufficiently to prevent their pistons from striking the heads under any conditions of air compression. An intercooler is provided in the base of the compressor.

AIR COMPRESSORS OF THE CURTIS & CO. MANUFACTURING
COMPANY, ST. LOUIS, MO.

In the following figures are illustrated the various styles of air compressors made by this company. They are principally designed for use in shops and foundries, and for the requirements of small operators with compressed air. In Fig. 159 is represented the duplex single-acting belt-driven compressor, which is built in two sizes, 6×6 and 8×8 inches, piston and stroke.

A section of the working parts is shown in Fig. 160, and the valve seat and valve cap in Figs. 161 to 164. The working parts are entirely enclosed in order to exclude the dust of a shop from the valves and cylinders. The trunk pistons are packed with metallic rings, and the cylinders and heads water-jacketed.

In Fig. 165 is represented the duplex single-acting compressor with a vertical steam engine all mounted on a single

base. In this arrangement the engine crank is set at right angles with the compressor cranks, so that the greatest resistance during compression receives the highest pressure in the steam cylinder.

The working parts of this compressor are shown in section on preceding page.

In Fig. 166 is shown a sectional elevation from the drawing

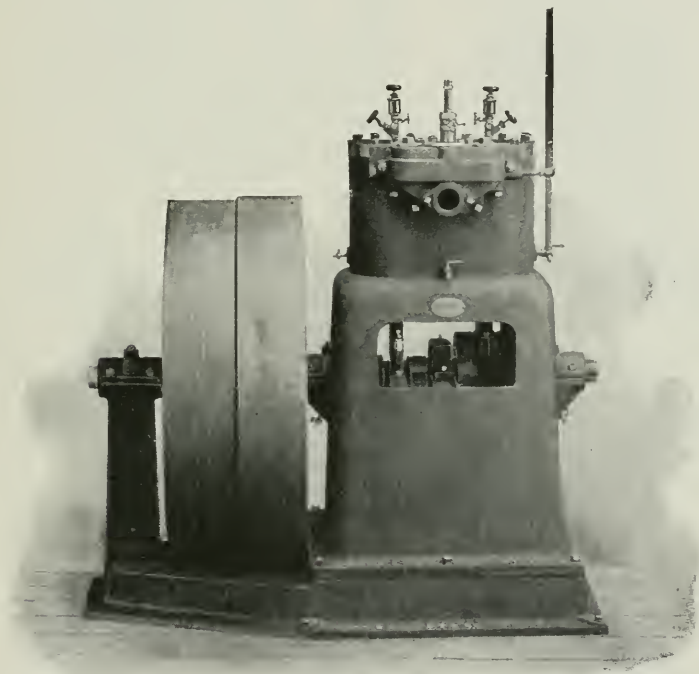


FIG. 159.--DUPLEX VERTICAL AIR COMPRESSOR

Belt driven.

of the belt-driven compound or two-stage compressor of the Curtis Company, the cylinders of which are 13 and 8 inches diameter by 12-inch stroke, with an intercooler shown in the vertical section on the next page.

The general construction and valves are the same as in other compressors of this company. Capacity at 120 revolutions is 100 cubic feet of free air per minute at 100 pounds pressure.

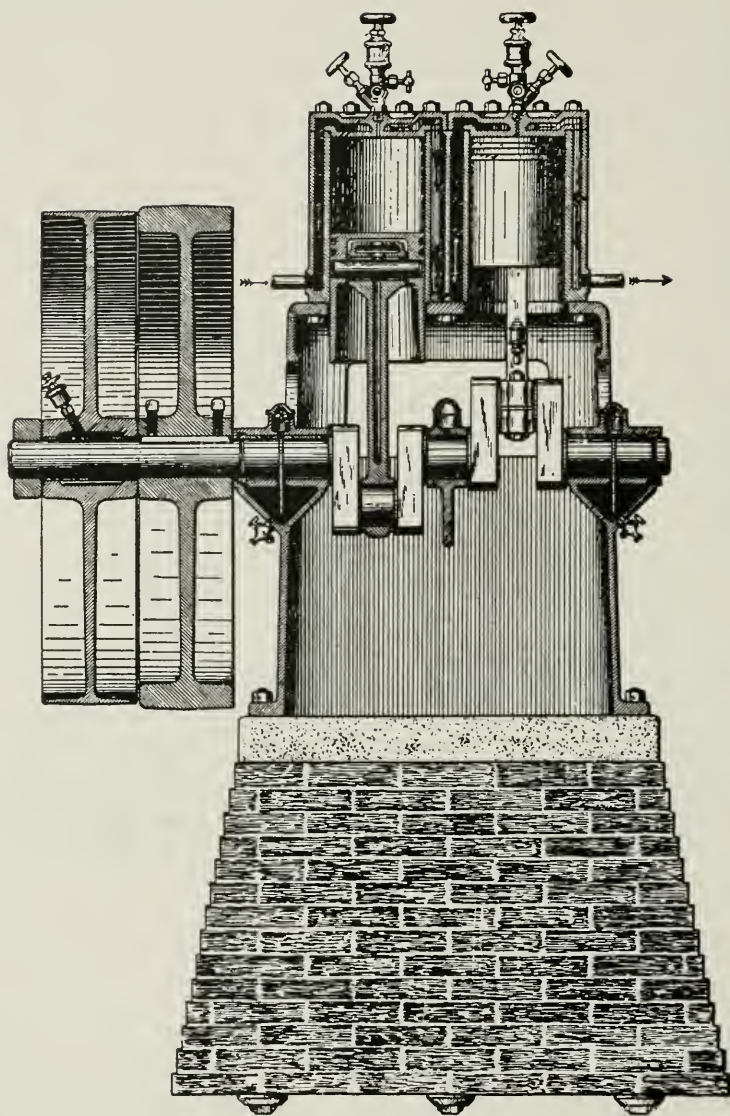


FIG. 160. — SECTION.

A larger size on the same plan has a capacity of 200 cubic feet per minute.

In Fig. 167 is a sectional end elevation of the smaller cylinder showing the air inlet from the intercooler, valve location,



FIG. 161.—VALVE.



FIG. 162.—VALVE.

and air discharge, figured on the same scale as the front section on previous page.

These compressors are provided with both an air-pressure and speed governor. The air-pressure governor automatically stops the compression of air without stopping the machine.

The gas and gasoline engine compressor of this company (Fig. 168) is a most compact arrangement suited for supplying compressed air for hammers and riveters in construction work.

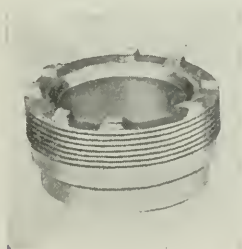


FIG. 163.—SEAT.



FIG. 164.—CAP.

The air cylinders are single-acting and connected by gearing to the gas or gasoline engine so that the engine makes two revolutions to one of the compressor. The cranks are so arranged that the motor stroke of the engine corresponds with the compressing stroke of the compressor. Cylinders of engine and compressor are water-jacketed. They are built for free-air capacity from 25 to 200 cubic feet per minute.

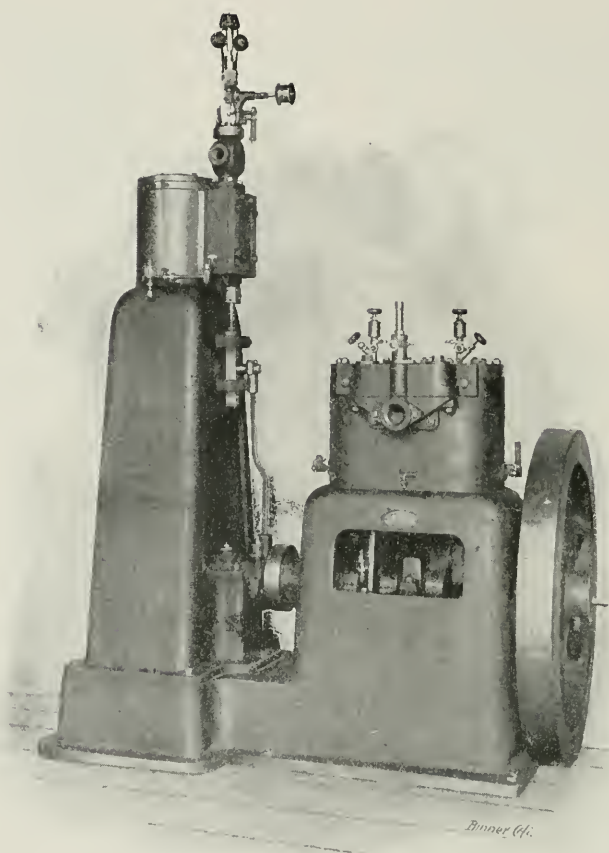


FIG. 165.—STEAM DRIVEN DUPLEX COMPRESSOR.

Mounted on common base.

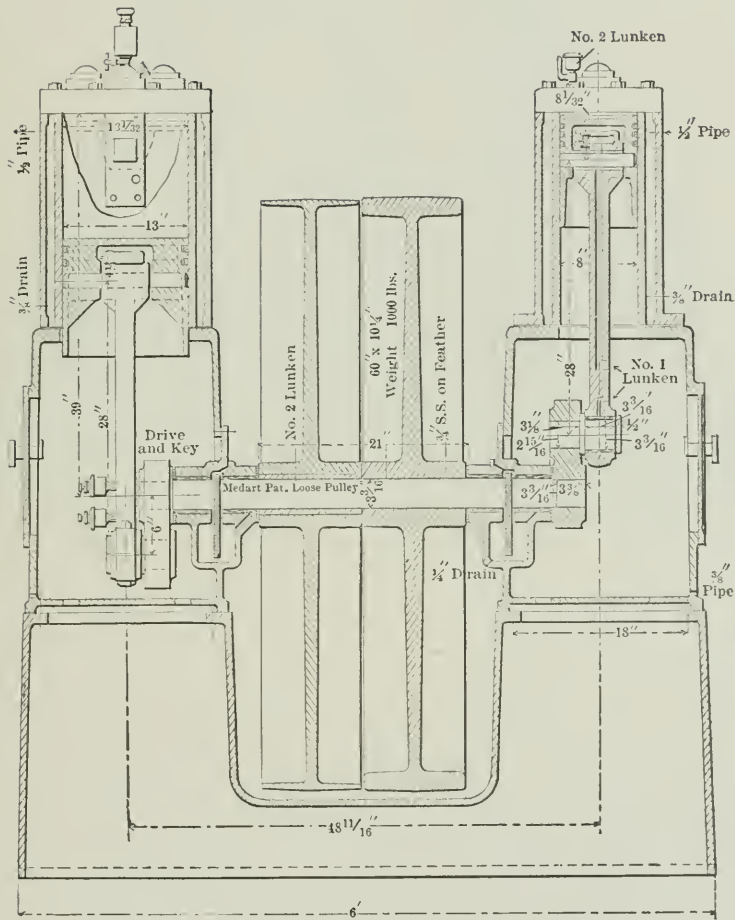


FIG. 166.—SECTION OF BELT-DRIVEN COMPOUND AIR COMPRESSOR.

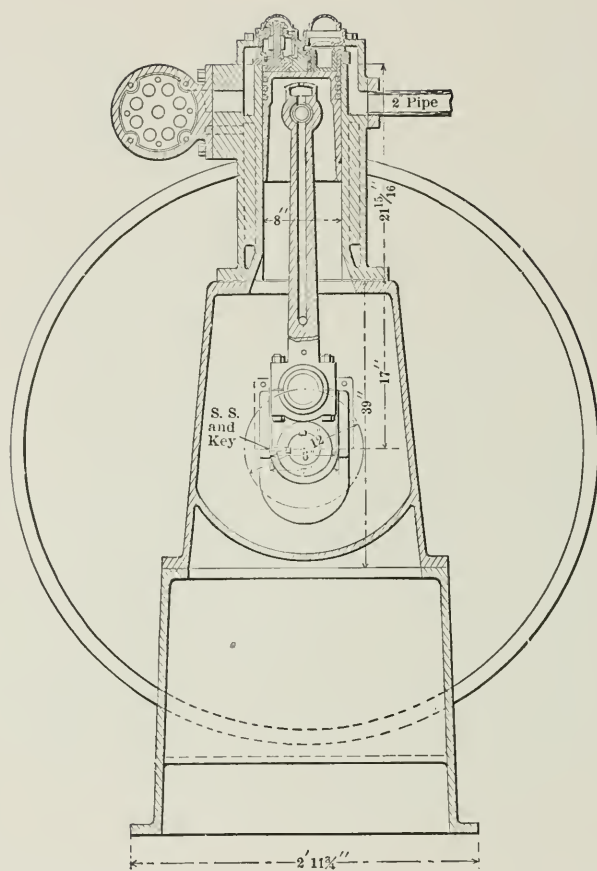


FIG. 167.—END SECTIONAL ELEVATION OF COMPOUND AIR COMPRESSOR.
Showing location of intercooler.

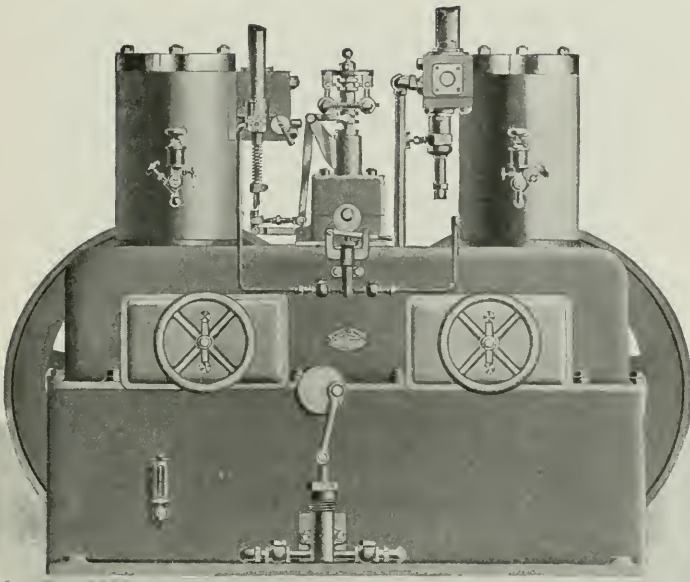


FIG. 168.—THE GAS-ENGINE AIR COMPRESSOR.

AIR COMPRESSORS OF THE NEW YORK AIR COMPRESSOR COMPANY.

The compressors of this company have been designed especially for supplying compressed air for the operation of pneumatic hammers, drills, riveters, hoists, and other tools used in shop and construction work, although equally applicable to driving rock drills, coal-cutters, and other mining machinery, pumping water by the air-lift system, operating signals, cleaning cars and cushions, elevating acids, and other uses of compressed air.

The Corliss type of compressor shown in Fig. 169 is employed in installations of large capacity, and is built with

duplex or compound steam or air cylinders, either condensing or non-condensing.

The compressor shown in Fig. 170 has duplex steam cylinders with Meyer adjustable cut-off, and compound air cylinders

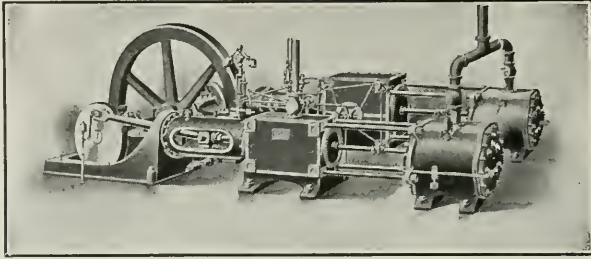


FIG. 169.—THE CORLISS TYPE.

with intercooler. This compressor is built in four sizes, ranging in capacity from 500 to 2,000 cubic feet of free air per minute, and when the available steam pressure is sufficiently high the steam cylinders are compounded also. The intercooler consists of a set of composition metal tubes encircled by a steel

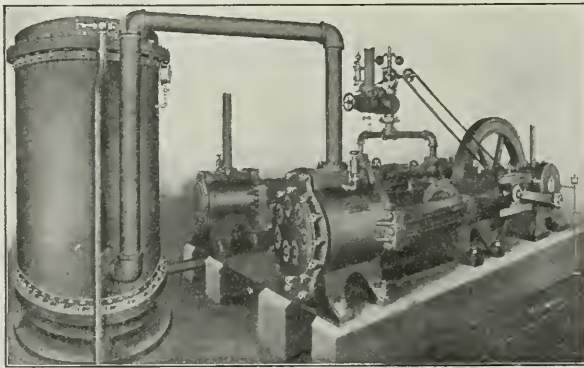


FIG. 170.—THE DUPLEX TYPE.

shell, the cooling water passing through the tubes and the air circulating around them.

The duplex steam-driven air compressor of this company is illustrated in Fig. 171. It has cylinders and heads water-jacketed, and is provided with both speed and pressure control-

lers. The large sizes are built with the Meyer adjustable cut-off, a most substantial and efficient compressor for any work.

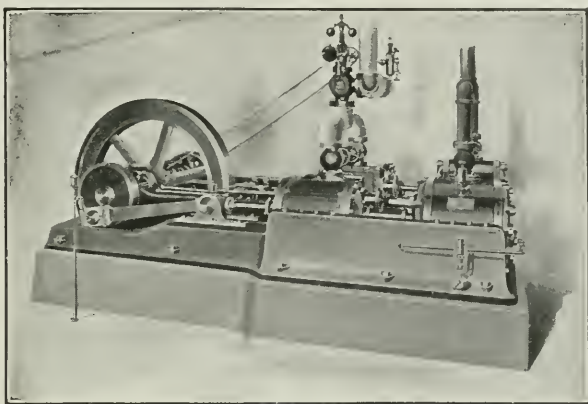


FIG. 171.—DUPLEX TYPE WITH GOVERNOR.

They are made in sizes of 7×7 -inch air cylinders with equal-sized steam cylinders, and in five sizes up to 16×18 -inch air cylinders with equal-sized steam cylinders, and of capacity from 80 to 1,000 cubic feet of free air per minute.

Fig. 172 represents a single straight-line steam-driven air compressor, also built by the same company. This type is ad-

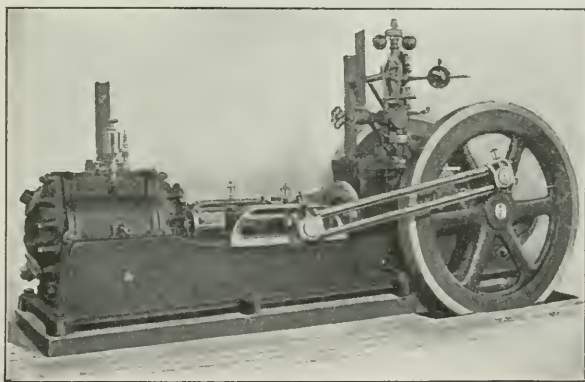


FIG. 172.—STRAIGHT-LINE COMPRESSOR.

vantageous for field work and for other classes of service presenting conditions rendering the single style of compressor preferable to the duplex.

Fig. 173 illustrates a horizontal, duplex, belt-driven air compressor with air-pressure controller that unloads the work of the compressor whenever an over-pressure is attained by the

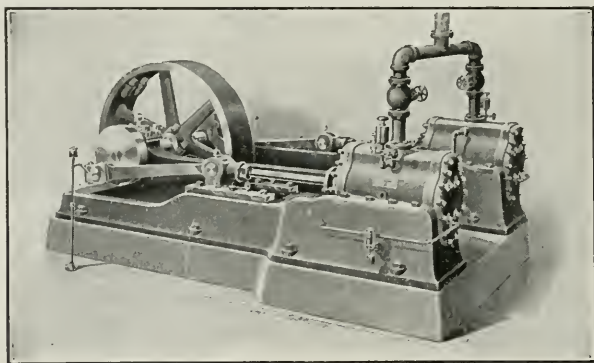


FIG. 173.—DUPLEX BELT COMPRESSOR.

stoppage of work on air tools. They are made in air-cylinder sizes from 7×7 to 16×18 inches, and of capacity from 80 to 1,000 cubic feet of free air per minute.

The single style of belt-driven air compressor shown in Fig. 174 is adapted to the same service as the duplex machine last

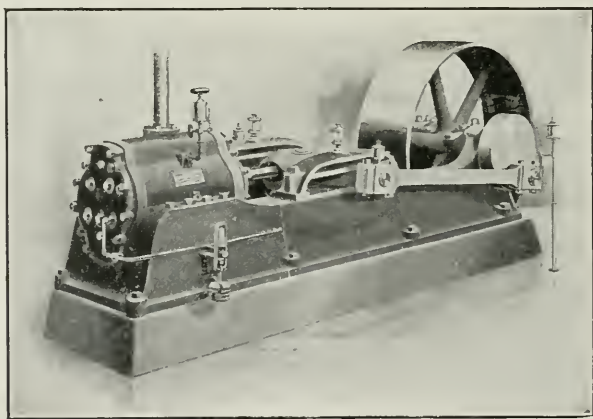


FIG. 174.—SINGLE BELT COMPRESSOR.

described, and is sometimes preferred because of the more limited floor space occupied by it. This compressor is built in sizes ranging from 100 to 500 cubic feet of free air per minute,

and is provided with automatic unloading device for controlling its operation to suit the demand made upon it.

The vertical air compressor, belt-driven (Fig. 175), is pro-

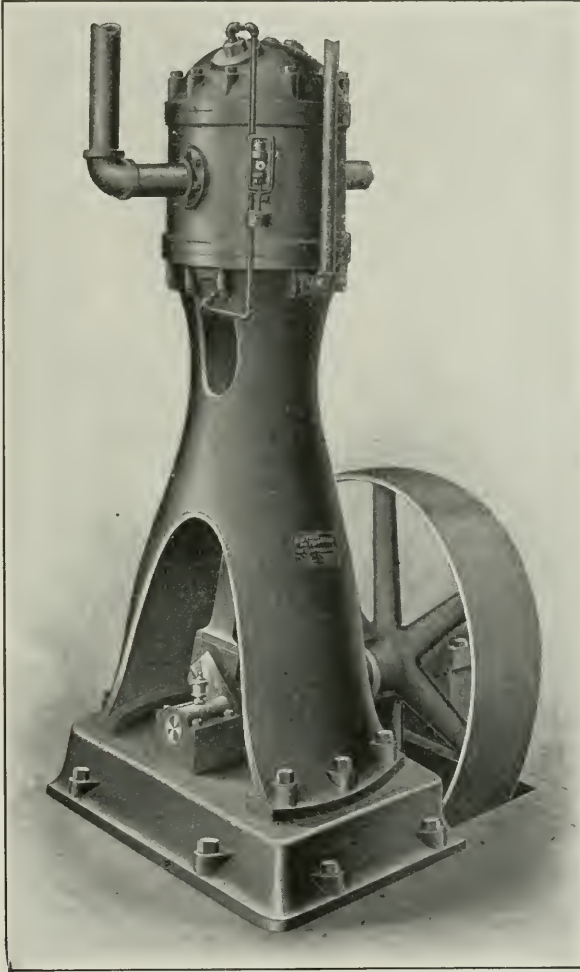


FIG. 175.—THE VERTICAL AIR COMPRESSOR.

vided with water-jacketed cylinders and heads; a substantial machine, with poppet valves, and suitable for any pressure used in shop and constructive work.

Chapter XXI.

AIR COMPRESSORS—Continued

AIR COMPRESSORS.

(Continued.)

AIR COMPRESSORS OF THE RAND DRILL COMPANY,
NEW YORK CITY.

FIGS. 176 and 177 show the standard forms of the air cylinders of this company, which are water-jacketed, and in some of the designs the heads are also water-jacketed. Valves are of the poppet type.

The unloading device by the opening of a valve from excessive pressure allows the air on the compression side of the pis-

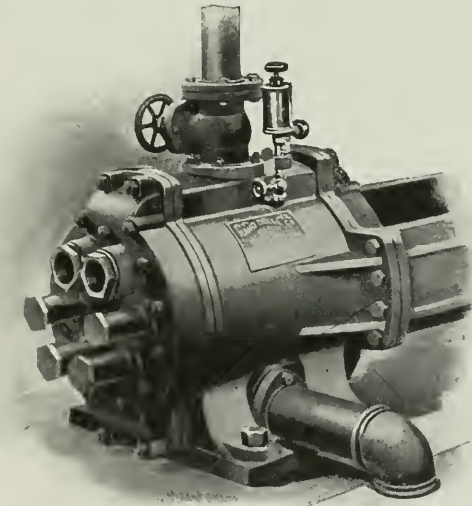


FIG. 176.—AIR CYLINDER WITH HOODED HEADS AND POPPET VALVES.

ton to pass over to the inlet side and thus relieve the piston of its load until the receiver pressure falls below the working pressure, when the weight closes the valve and the compressor resumes its work.

The air-valve gear of this company is a novelty in valve control. Experience has shown that the ordinary poppet valves

as usually held under a spring are liable to chatter more or less, and that by making the springs stronger to reduce the chattering the lift of the valves is also reduced, which restricts admission, and therefore a larger number of inlet valves are required or the efficiency of the compressor is lessened.

The mechanical poppet-valve gear shown at Fig. 179 has a yoke frame at each end of the cylinder connected by outside rods. To the yoke frames the inlet and outlet valves are con-

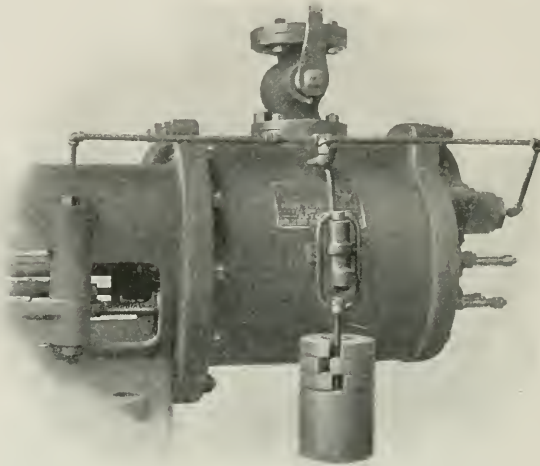


FIG. 177.—THE UNLOADING DEVICE FOR A BELT COMPRESSOR.

nected, not rigidly, but with spring tension, so that all the valves have a positive movement at the proper moment to a wide-open or closed position, the springs operating to soften the impact of the valves. The valve gear is operated from an eccentric on the main shaft.

The valves thus operated have their equivalent area largely augmented, and thus require a less number of valves to a cylinder than when fitted with the ordinary poppet valve with springs only.

In Fig. 181 is illustrated the complete cross compound Corliss air compressor of the Rand Drill Company, in which the low-pressure cylinder is provided with the Corliss inlet valve, the

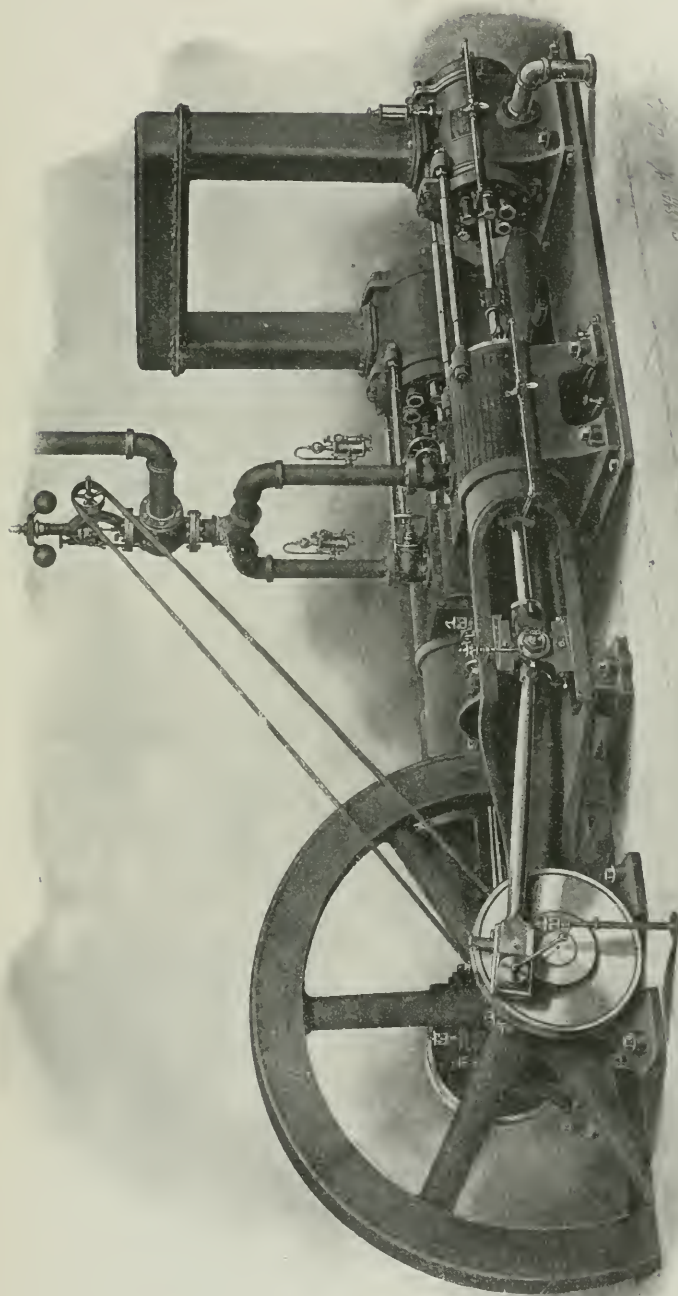


FIG. 178.—DUPLEX STEAM AND CROSS COMPOUND AIR CYLINDERS.
With intercooler and steam governor. Rand Drill Company.

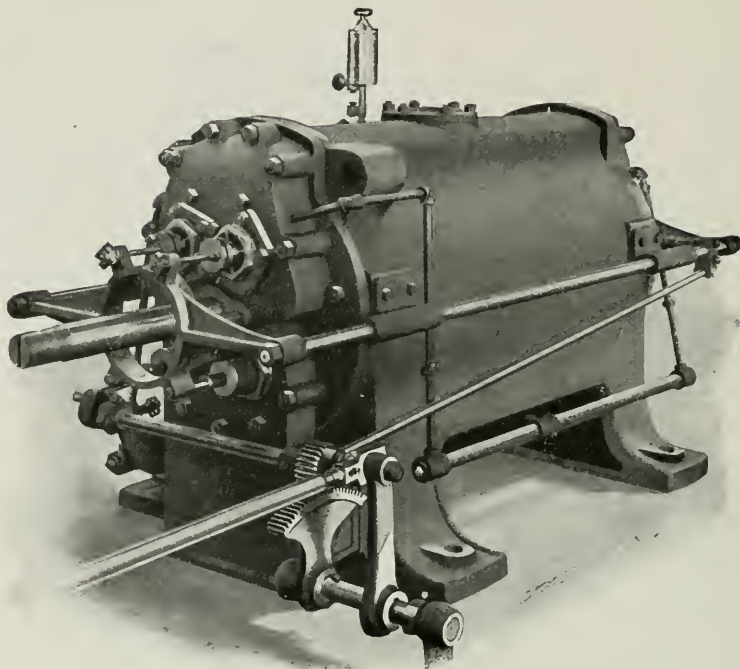


FIG. 179.—THE RAND AIR VALVE GEAR.

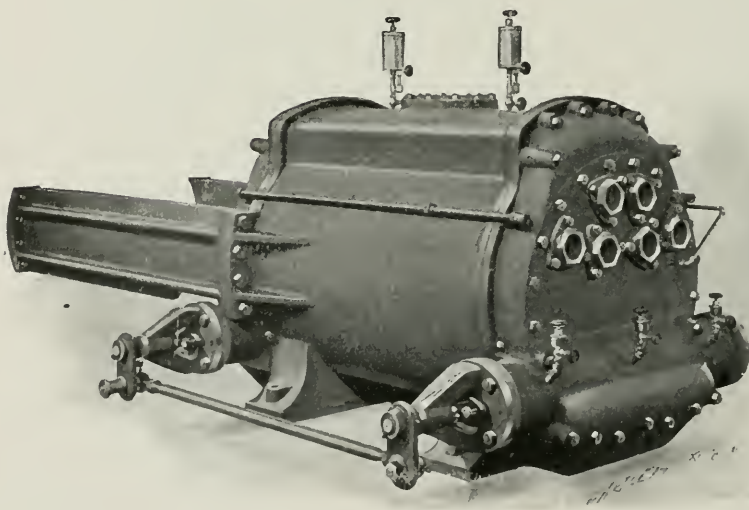


FIG. 180.—THE CORLISS INLET VALVE ; POPPET DISCHARGE VALVES.

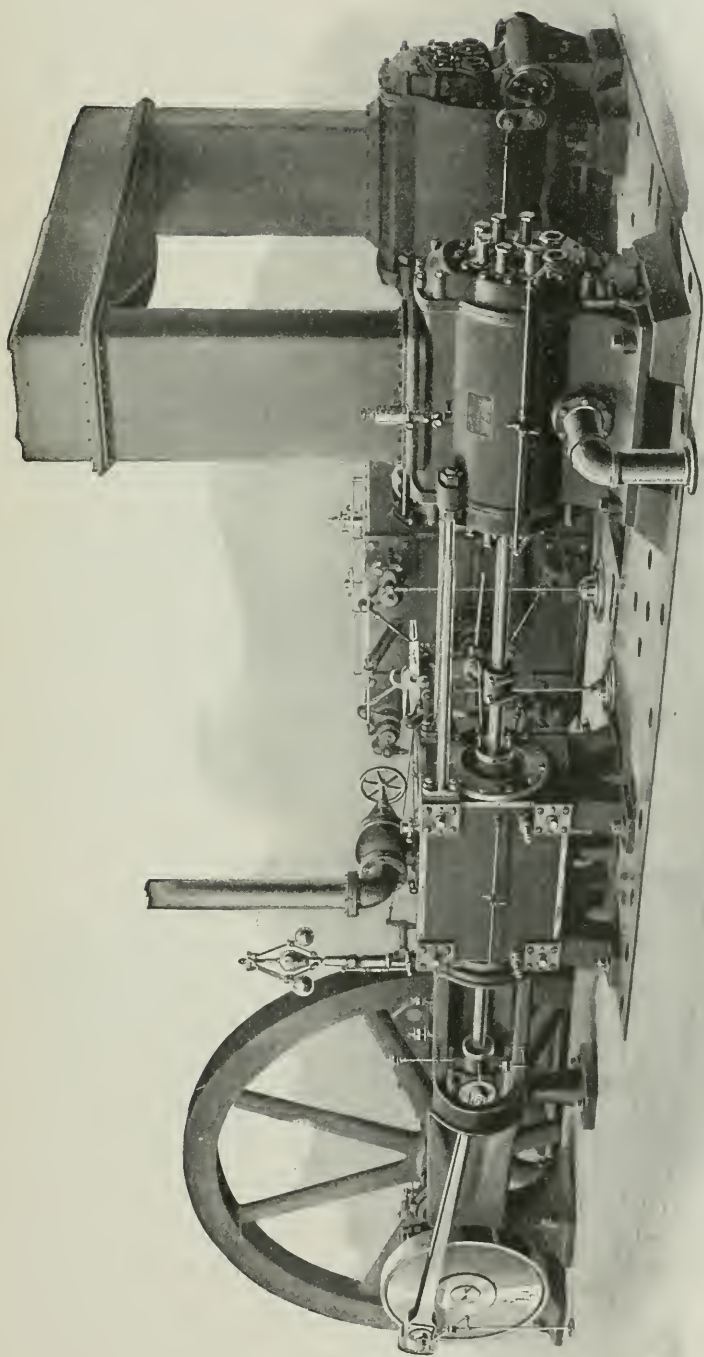


FIG. 181.—CROSS COMPOUND STEAM AND CROSS COMPOUND AIR CYLINDERS.
Independent condenser. Corliss inlet valve on low-pressure air cylinder and Rand intercooler.

discharge and high-pressure valves being of the free poppet type. The box-like connection between the cylinders contains the intercooling pipe coil as shown in the section on intercooling.

Fig. 183 represents the cross compound steam and air cylinder type of this company, with removable water jackets on the air cylinders—a valuable consideration for the efficiency of an

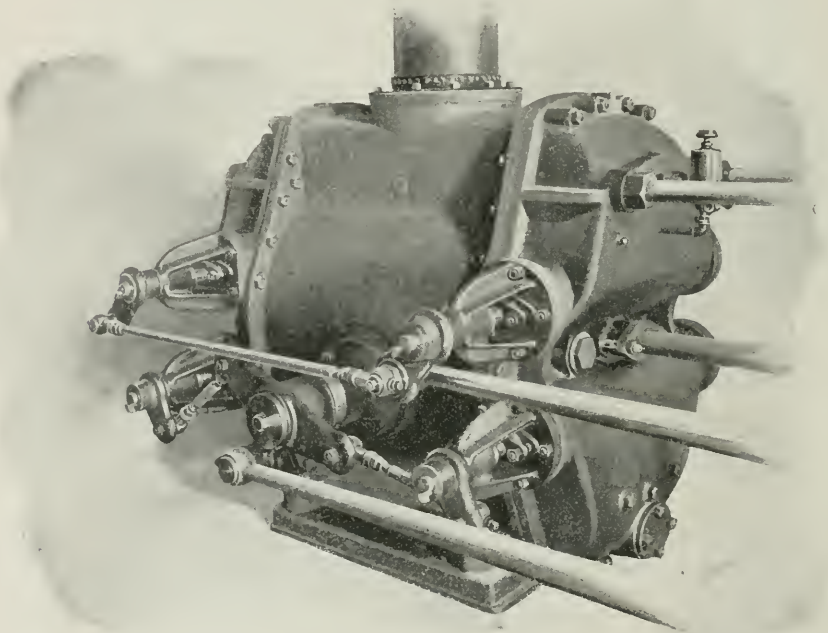


FIG. 182.—AIR CYLINDER; CORLISS INLET AND DISCHARGE VALVES.

air compressor where limy or muddy water must be used for cooling cylinders and intercooler.

In the various sizes and combinations of the compressors of the Rand Drill Company, numbering about twenty, the capacities vary gradually from 350 to 6,000 cubic feet of free air per minute. The compound or two-stage compressors are intended for final pressures up to 100 pounds pressure per square inch. In the low-pressure cylinder, compression takes place from atmospheric pressure to 27 pounds, delivering to the inter-

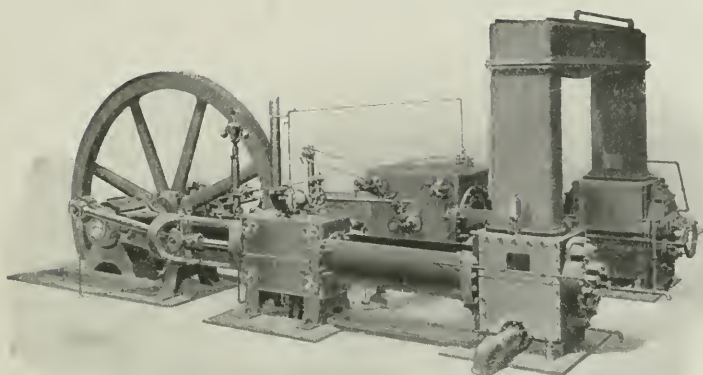


FIG. 183.—CROSS COMPOUND STEAM AND AIR CYLINDERS.
With removable water jackets and intercooler.

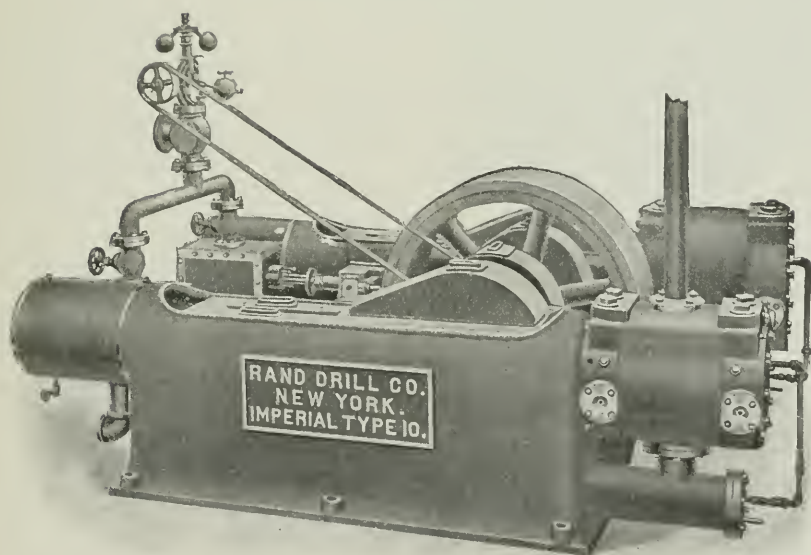


FIG. 184.—THE IMPERIAL TYPE AIR COMPRESSOR.

cooler at about 240° F. and to the high-pressure cylinder at normal temperature. When the full pressure of 100 pounds is obtained the air is delivered at a temperature of 240° F., or in the like proportion for other required working pressures, varying from 50 to 110 pounds per square inch.

A new design of self-contained duplex or compound air compressor has been brought out by the Rand Drill Company (Fig. 184), in which the steam and air piston rods are connected by a yoke within which the crank and connecting-rod are

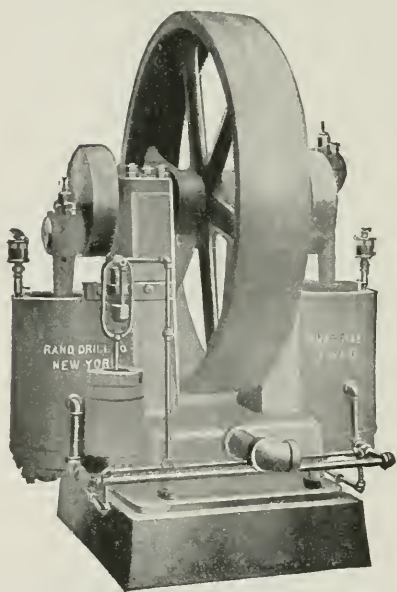


FIG. 185.—IMPERIAL BELT COMPRESSOR.

contained. Cranks at right angles, with heavy central fly-wheel, and all cylinders overhung. Inlet valves of Corliss type driven from eccentrics on shaft with poppet discharge valves. The bath system of lubrication is provided for the main bearings, crank pins, crosshead slides, and eccentric straps, the oil being distributed by the dip of the crank discs.

This type of compressor is made in six sizes with capacities from 140 to 1,000 cubic feet of free air per minute. The

fly-wheel has a broad face, crowned to receive a driving belt, so that the compressor may be driven by other machinery, or may drive other machinery if required.

The Imperial belt compressor of this company (Fig. 185) is of the vertical type with single-acting trunk pistons connected to cranks set opposite to each other. The belt pulley is very large and heavy with broad face to give ample power direct from the belt. For pressures above 25 pounds the cylinders are water-jacketed. Inlet and outlet valves are of the poppet type. The

inlet valves of both cylinders have a common passage which can be connected to an air pipe from outdoors for cool air free from dust. It is designed as a special air compressor for shop tools, hammers, chisels, riveters, etc., and has an unloading device that stops the compression of air without stopping the machine,

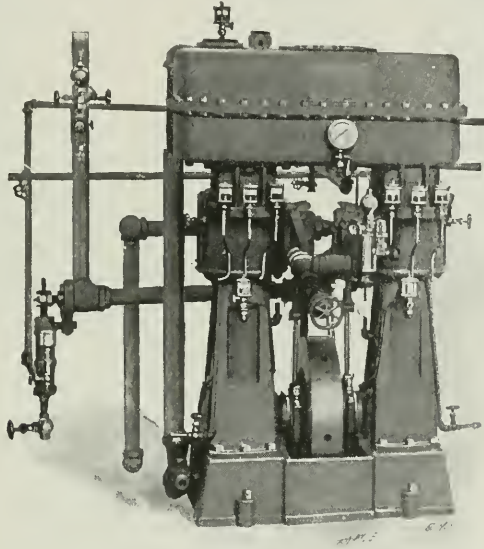


FIG. 186.—HIGH-PRESSURE COMPRESSOR.

when the pressure reaches its limit. It is made in seven sizes of capacity, from 11 to 275 cubic feet of free air per minute.

STEAM-ACTUATED HIGH-PRESSURE COMPRESSORS.

In Fig. 186 is illustrated the small vertical two-stage compressor with box water jacket for high pressures. In these compressors the entire air cylinders and connecting-pipes are covered with a large body of water, which insures a thorough cooling of the air or gas throughout the operation of compression. They are in use for the production of liquid carbonic acid gas, and work up to a thousand or more pounds per square inch.

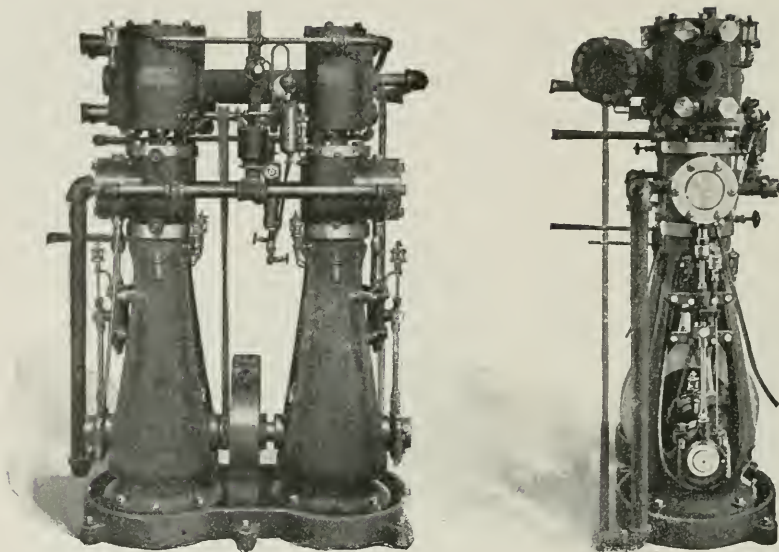


FIG. 187.—HIGH-PRESSURE COMPOUND COMPRESSOR.

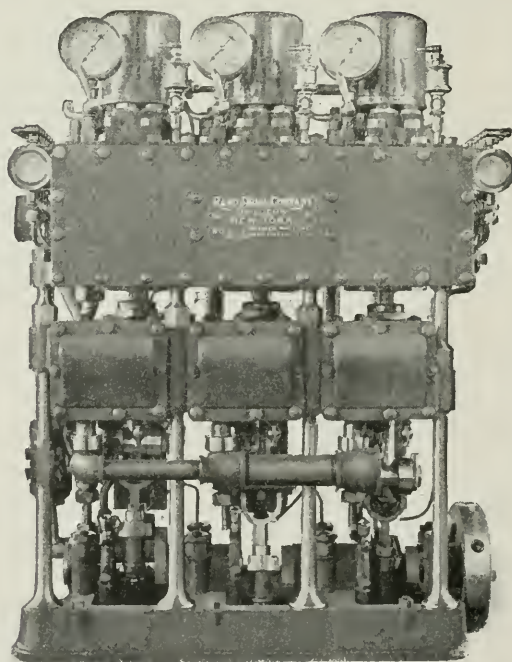


FIG. 188.—THREE-STAGE COMPRESSOR.

Fig. 187 represents the same style of compound compressor with jacketed cylinders and intercooler; front and side view.

In Fig. 188 is represented the three-stage, high-pressure, steam-actuated compressor of the Rand Drill Company for compressing air to very high pressures, 2,500 pounds or more. This type of compressor is much used for liquefying carbonic acid

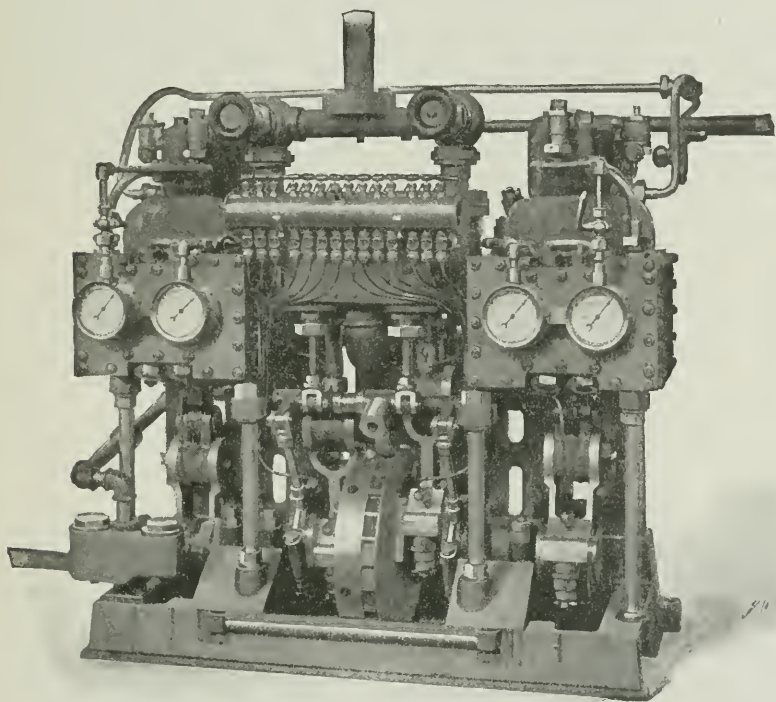


FIG. 189.—FOUR-STAGE AIR AND GAS COMPRESSOR.

gas and for compressing oxygen, hydrogen, and other gases for experimental work and for transportation in steel bottles.

Fig. 189 represents the four-stage air and gas compressor.

In Figs. 190 and 191 are illustrated the direct-acting air compressors of the Marsh type, built by the American Steam Pump Company. A model type of portable and light construction, suitable for operating pneumatic tools.

Fig. 192 represents the duplex vertical air compressor of the St. Louis Steam Engine Company.

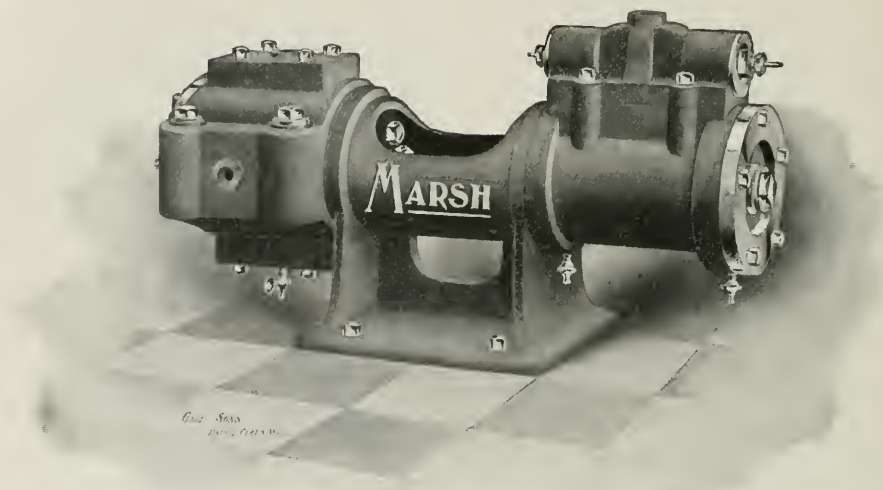


FIG. 190.—AIR COMPRESSOR, AMERICAN STEAM PUMP COMPANY, BATTLE CREEK, MICH.
Direct acting.

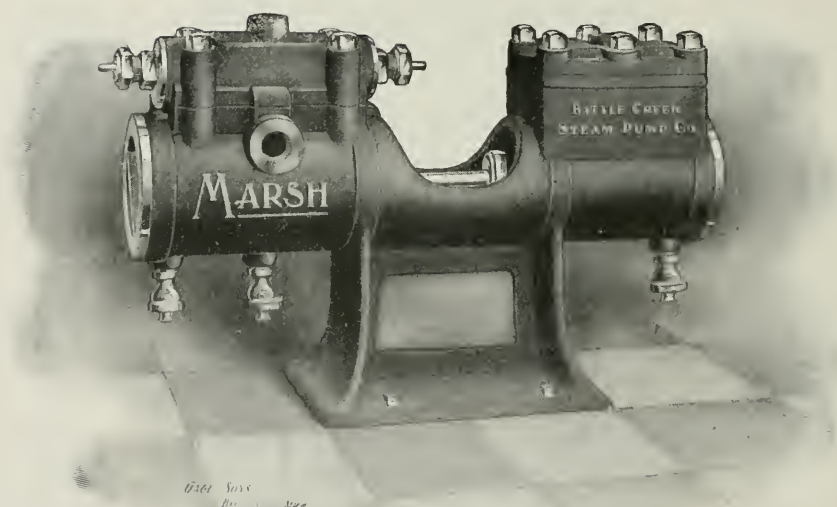


FIG. 191.—AIR COMPRESSOR, AMERICAN STEAM PUMP COMPANY.
Direct acting. Smallest size, $2\frac{1}{2} \times 2$ -inch air cylinder.

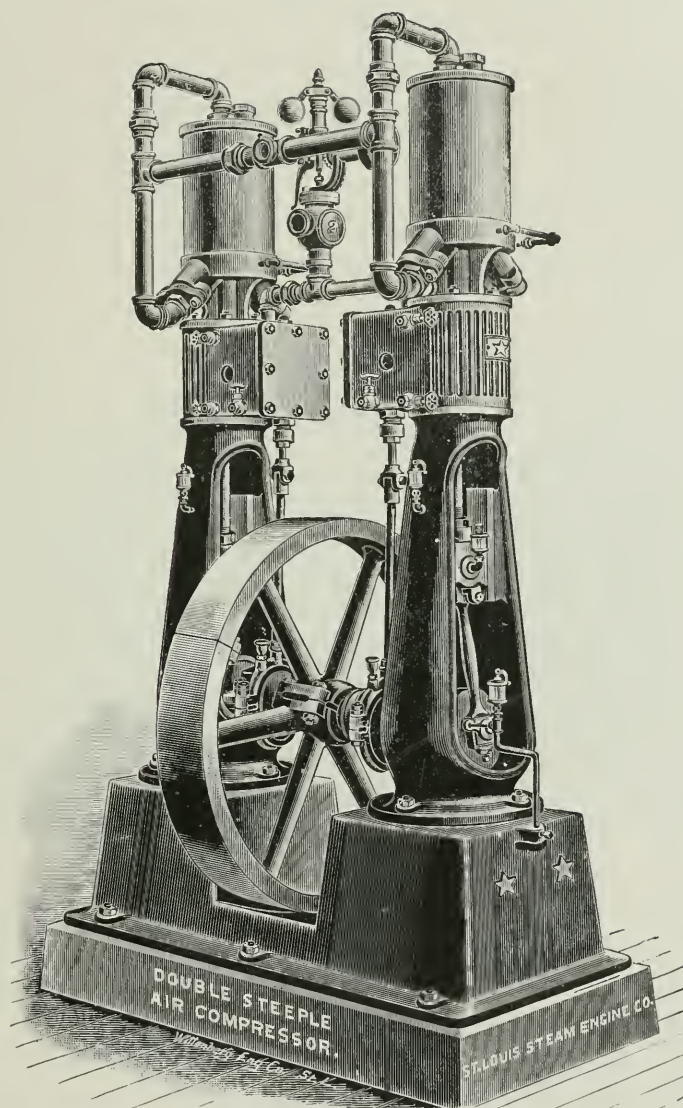


FIG. 192.—VERTICAL DUPLEX AIR COMPRESSOR.

St. Louis Steam Engine Co. Three sizes built—6 x 6, 7 x 7, 8 x 8. Supplying from 50 to 120 cubic feet of free air per minute.

AIR COMPRESSORS AND BLOWING ENGINES OF THE PHILADELPHIA ENGINEERING WORKS, LTD.

This company's air compressors and blowing engines for blast furnaces are fitted with the Corliss steam and Gordon air-valve gear. In Fig. 193 is shown the operation of the positive valve system in these compressors. The inlet valves are opened and closed by an eccentric operating directly through

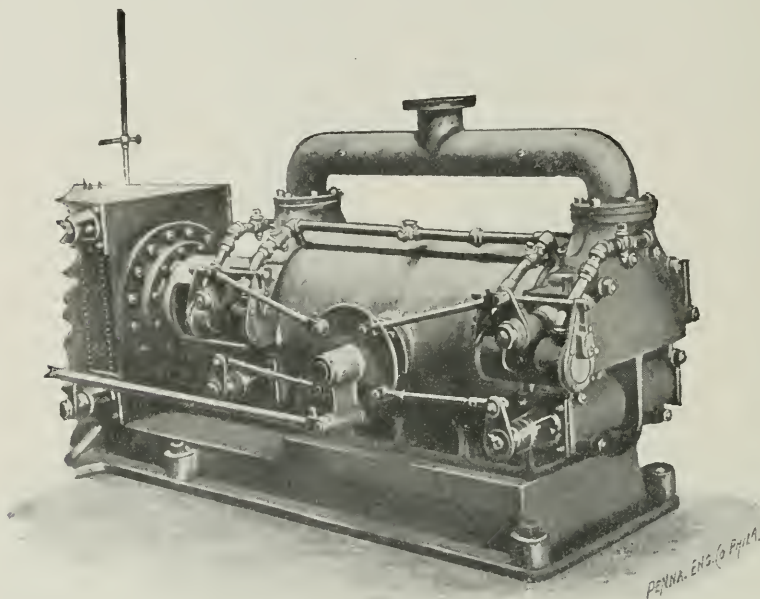


FIG. 193.—THE CORLISS AIR COMPRESSOR CYLINDER.
With Gordon valve movement.

the wrist plate. The outlet valves are operated by the same wrist.

The outlet valves are opened when the pressure within the cylinder reaches that of the discharge, and are closed from the action of the same wrist plate that operates a spool piston in an auxiliary cylinder for each discharge valve, one end of which is larger than the other. The larger end is in constant connection with the compression cylinder and the smaller end with

the discharge chamber, the office of which is to relieve the friction on the Corliss valve and throw it wide open at the moment that the pressures in the cylinder and discharge chamber are equal.

A HYDRAULIC-CONTROLLED DIRECT-ACTING AIR COMPRESSOR.

In Fig. 194 is represented a new departure in the construction of direct-acting air compressors.

The D'Auria air compressor is a non-rotative compressor of the duplex type. So far as steam economy is concerned, it may

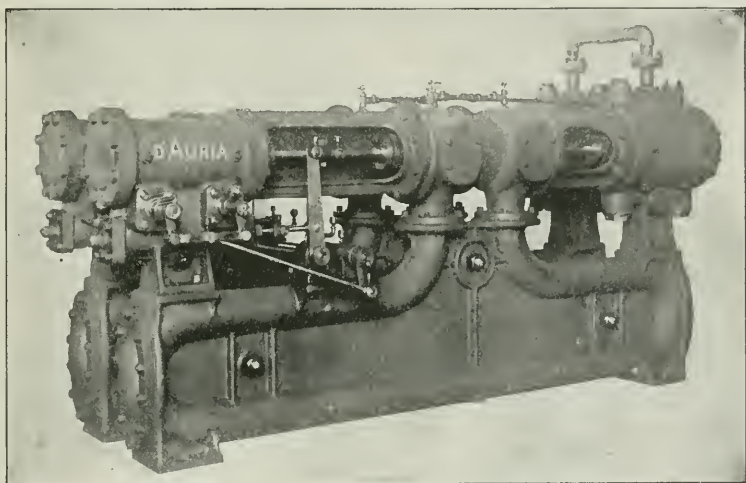


FIG. 194.—D'AURIA NON-ROTATIVE AIR COMPRESSOR.

be said to have less limitations than even a crank and fly-wheel compressor, for the simple reason that, while in the latter the high degree of steam expansion calls for heavier fly-wheels, heavier crank shafts, etc., the moving parts of the D'Auria compressor are not in the least affected by the degree of steam expansion, and the machine works equally well with a high or with a low expansion.

Since there is no mechanism of fly-wheels, connecting-rods, and crossheads employed to equalize the propelling force and the resistance at every point of the stroke, the question arises,

How is perfectly smooth action attained in the D'Auria compressor, starting the stroke with a high initial pressure of steam against no resistance, and ending the stroke with a propelling force practically *nil* and with resistance at a maximum?

This result is accomplished by a "hydraulic compensator," which is a cylinder, *A A*, Fig. 195, fitted with a plunger, *B*, carried by the same piston rod which connects the steam and the air piston. The ends of the compensator cylinder communicate with each other by means of a loop of pipe, *C C C*, turned

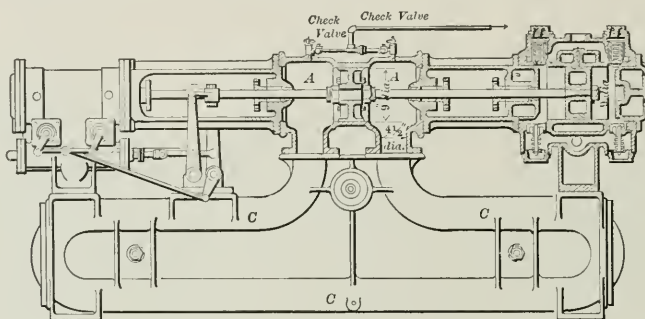


FIG. 195.—SECTION D'AURIA AIR COMPRESSOR.

into the form of a very rigid bed-plate, which adds to the strength of the machine and preserves, under all conditions, the alignment of the piston rod. This cylinder and pipe are filled with water or any other liquid; and as there is no loss of liquid beyond that which may leak through the stuffing-boxes, they are easily kept full from any source of water supply, through the small pipe and two check valves, shown in Fig. 195.

When the compressor is in action, the liquid column contained in the compensator pipe is affected reciprocally, to and fro, by the plunger, and acts in exactly the same manner as a balance wheel in a watch, taking up the excess of energy in the first half, and giving it back in the second half of the stroke with an exceedingly small loss due to friction.

These compressors have no dead centres. The cycle of their action being limited to the period of one stroke, they are able to

start and stop instantly, and, if fitted with a sensitive pressure regulator, will stop completely on a small variation of air pressure, and will start promptly when that pressure falls slightly below the normal. They are also built with compound steam and air cylinders.

These compressors are the invention of Mr. Luigi d'Auria, of Philadelphia, and are manufactured by the D'Auria Pumping Engine Company, Drexel Building, Philadelphia, Pa.

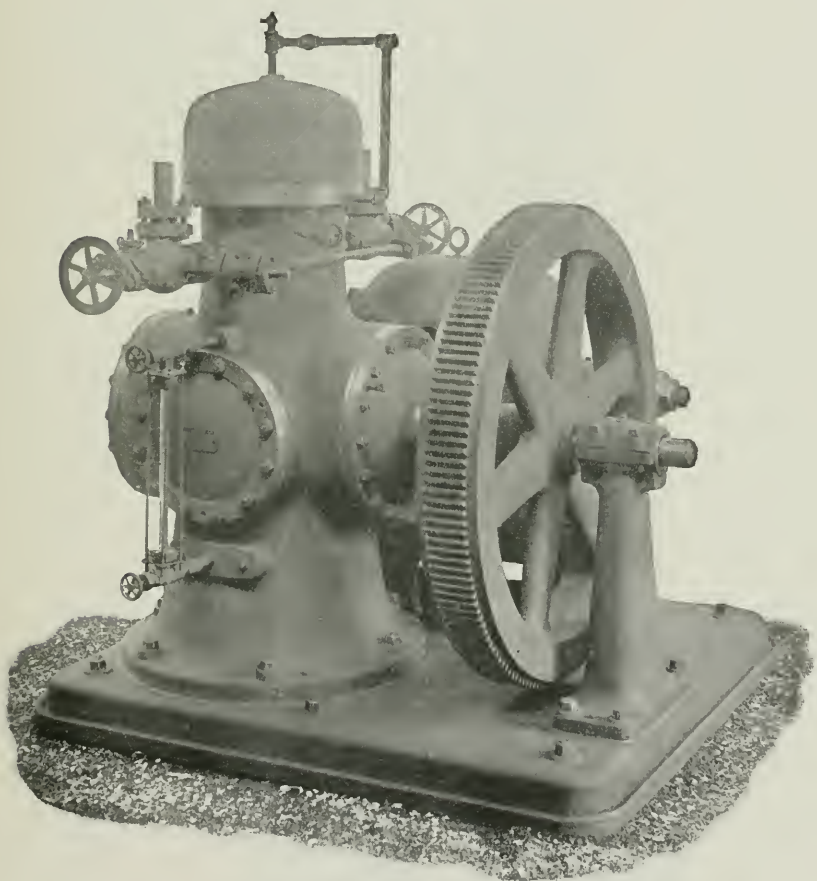


FIG. 196.—THE ELECTRIC-DRIVEN AIR COMPRESSOR.

Vertical type, directly geared to an electric motor. Built in seven sizes, single, of free-air capacity from 5 to 170 cubic feet per minute.

AIR COMPRESSORS OF THE STILLWELL-BIERCE & SMITH-VAILE
COMPANY, DAYTON, OHIO.

These air compressors are built in several combinations and of a large number of sizes, from 20 to 1,400 cubic feet of free air per minute.

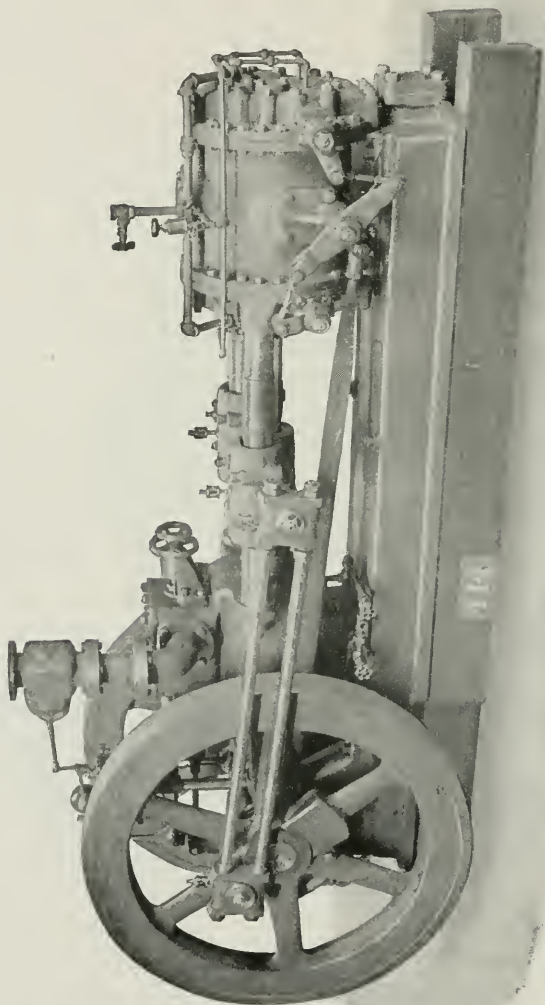


FIG. 197.—THE STRAIGHT-LINE AIR COMPRESSOR.

With mechanically operated inlet valves and Meyer-Wirtz adjustable cut-off. Automatic unloading device at maximum working pressure.

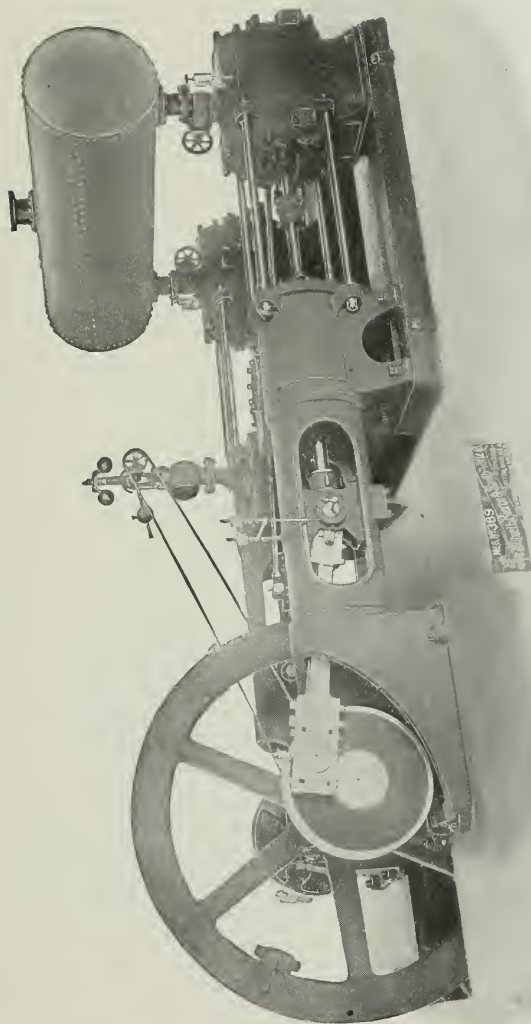


FIG. 198.—THE SMITH-VAILE DUPLEX AIR COMPRESSOR.
Inlet air valves Corliss type. Poppet discharge valves. Air receiver mounted over air cylinders.

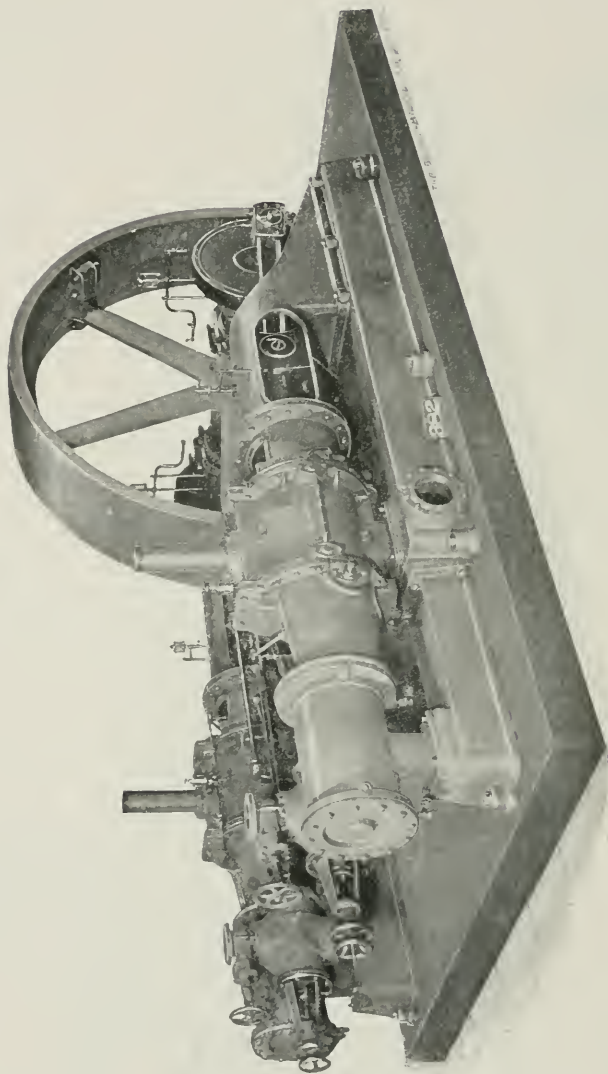


FIG. 199. STILLWELL-BIERCE & SMITH-VAILE DUPLEX AIR COMPRESSOR.
With mechanically operated inlet valves and Meyer-Wirtz adjustable cut-off.

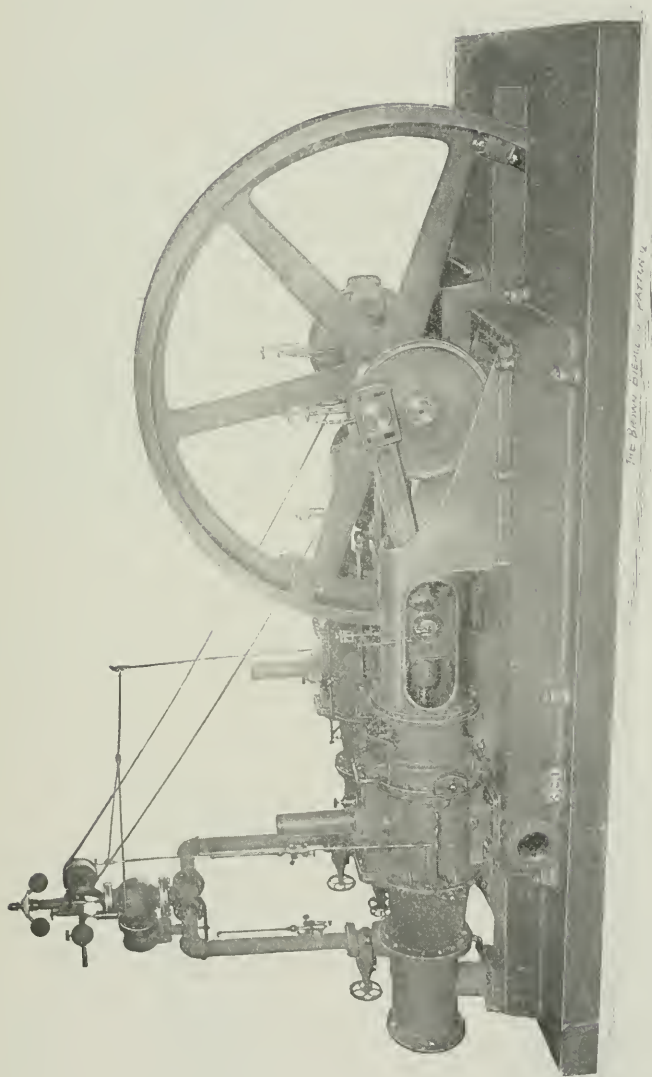


FIG. 500.—STILLWELL-BIERCE & SMITH-VAILE DUPLEX AIR COMPRESSOR.
Side view.

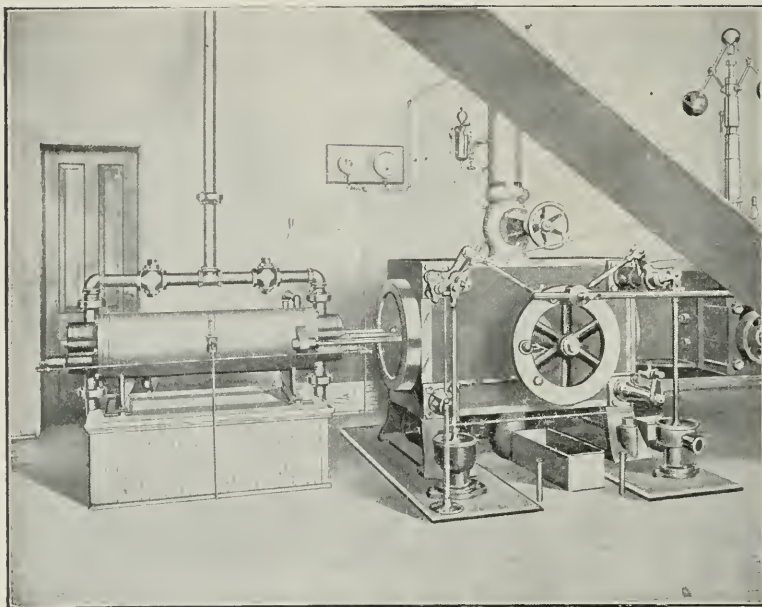


FIG. 201.—THE FISHER AIR COMPRESSOR.

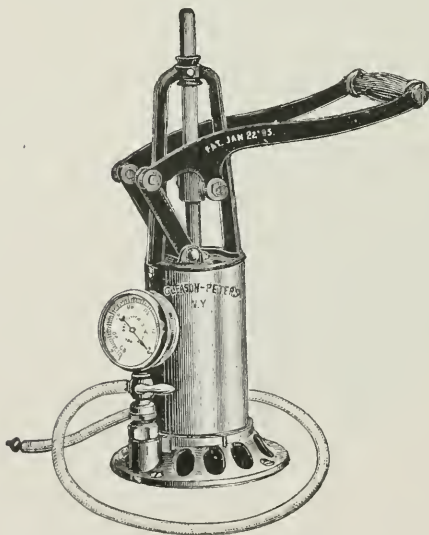


FIG. 202.—LEVER AIR PUMP.

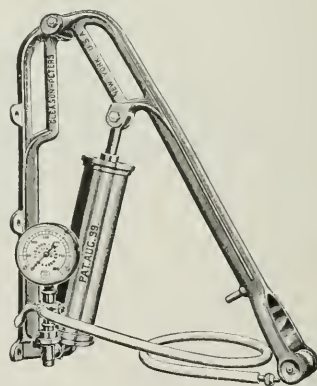


FIG. 203.—POST LEVER AIR PUMP.

In Fig. 201 we illustrate the Fisher air compressor made by the Sedgwick-Fisher Company, Chicago, Ill. Its principal novelty is the facility of its attachment to any engine by extending the engine piston rod through the back head and connecting it to the piston rod of the compressor, the air cylinder being connected by stay rods to the back head of the engine. This seems to be a most economical method of installing a compressed-air plant in shops and mills where the engine is not doing full duty. The plant as illustrated is in operation in S. Freeman & Sons' Works at Racine, Wis.

Apart from the bicycle air pump for its special work, there is no small air compressor so convenient for quick service as the table pump (Fig. 202), and the post pump (Fig. 203). The first can be screwed to a table or bench, and the second can be screwed to a post, for any service under 150 pounds pressure per square inch. They are furnished by the Gleason-Peters Air Pump Company, New York City.

The action of the lever is such that the leverage increases with the increase of pressure by compression, a most desirable requisite in a hand-operated air pump. The air capacity is about 36 cubic inches of free air per stroke.

AIR COMPRESSORS OF THE NORDBERG MANUFACTURING COMPANY, MILWAUKEE, WIS.

We illustrate in Fig. 204, and following, the air compressors of the above company and the leading features of their design. The valve gear consists of a triple wrist arm running on a strong trunnion bolted to the cylinder, an eccentric on crank shaft connected to the wrist arm by an intermediate carrier arm. The connecting rods between the wrist arm and the valve arms are arranged for a quick and full opening and closing of the inlet valves, while the setting of the valves is made by adjusting screws on the hub of the valve arms.

In Fig. 205 is shown the unloading device, which is a re-

leasing mechanism which permits the regular operation of the inlet valves so long as the air pressure does not exceed the normal. When this pressure is exceeded the trip on the suction valves is released and the valve left wide open, relieving the compressor of its load. This is effected by a loaded plunger

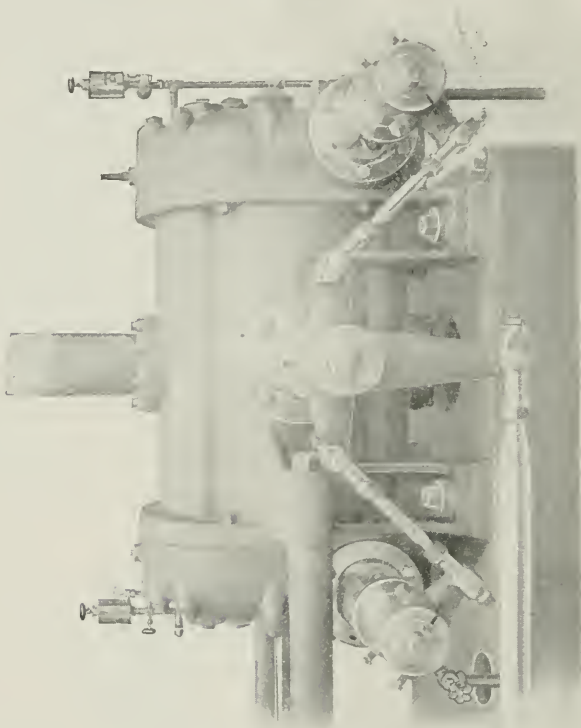


FIG. 204.—SINGLE-STAGE AIR CYLINDER WITH CORLISS VALVE GEAR AND INLET VALVES.

subject to the air pressure which acts upon a set of knock-off cams, in action similar to the release hook of the Corliss gear.

The combined pressure and speed regulator of this company (Fig. 208) consists of a frictionless plunger loaded with a spring and weight, and a centrifugal governor. These two mechanisms are connected to a floating lever in such a manner that they

can act independently of each other on the expansion gear of the engine, the adjusting rod of which is also connected to the floating lever. The centrifugal governor is extremely static, to such a degree that the speed required to lift it to its highest position is four times that necessary to just raise it clear of the

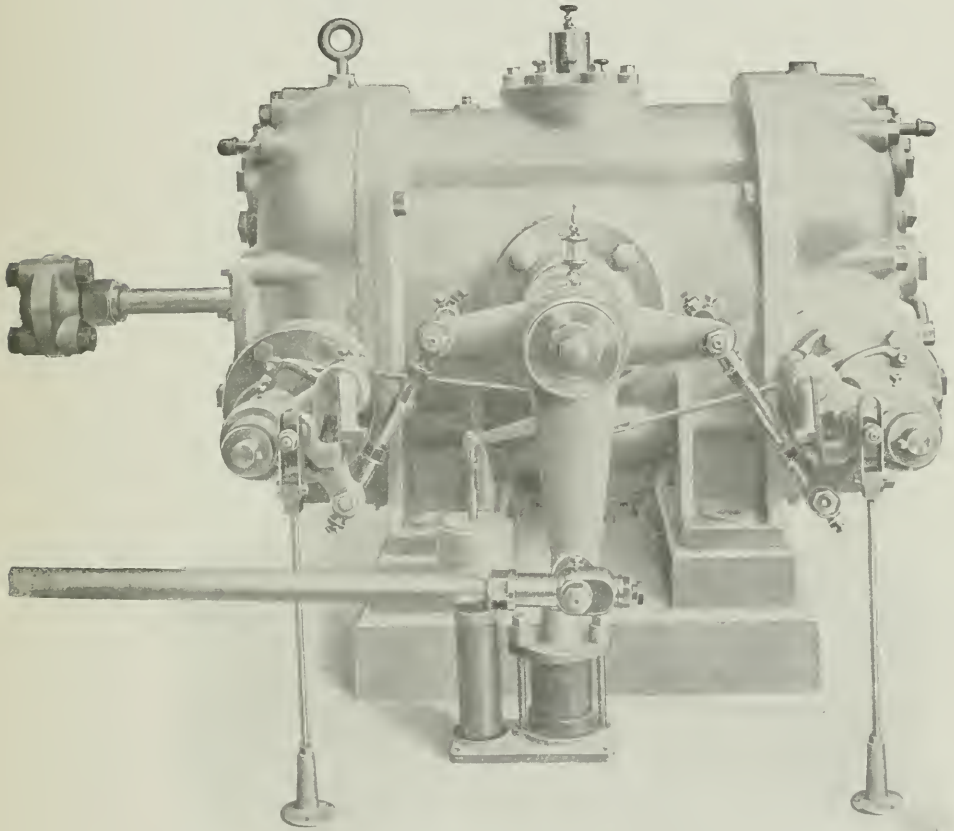


FIG. 205. THE UNLOADING DEVICE.

sustaining collar. The plunger is actuated by the air pressure, which is counteracted principally by the weight, while the spring pressure is only sufficient to produce a slightly increasing resistance as the plunger is depressed. The connection between the two elements of regulation and the expansion gear

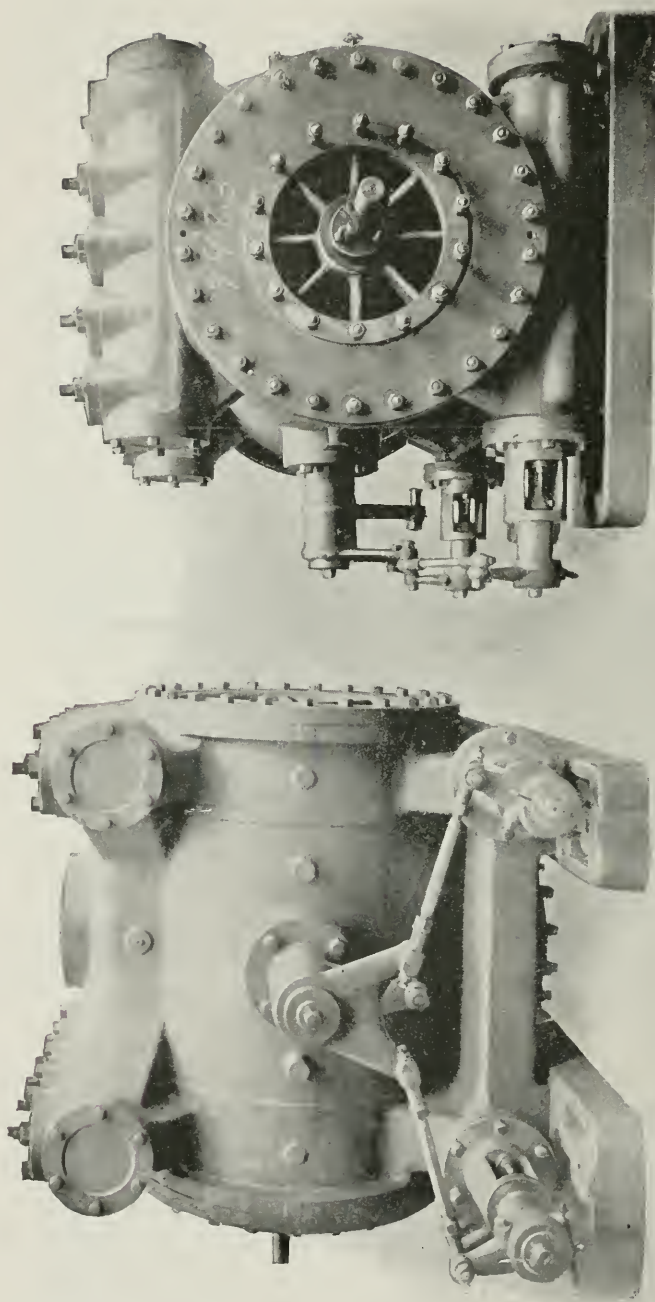


FIG. 206.—COMPRESSOR CYLINDER WITH CORLISS INLET VALVES AND VERTICAL DISCHARGE VALVES ON BODY OF CYLINDER.

is such that a rise of the governor (or increase of engine speed) and an increase of air pressure produce the same effect, viz., a shorter cut-off. In a well-designed compressor the mean effective air pressure, and consequently the mean effective steam

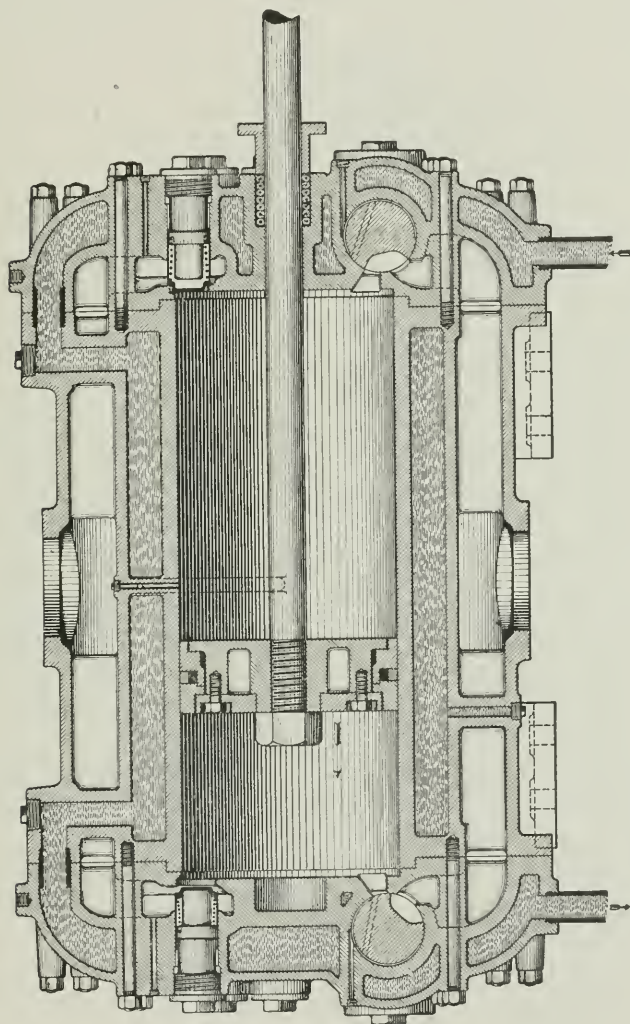


FIG. 207.—SECTION SHOWING CORLISS INLET VALVES AND POPPET DISCHARGE VALVES; ALL ENCASED FOR PIPE CONNECTIONS.

pressure, is practically the same at all speeds, and the point of cut-off is therefore fixed and independent of the speed. Bearing in mind this fact, the action of the governor will be readily understood. When the pressure tends to drop, due to

an increased consumption of air, the plunger is forced higher up into its barrel by the action of the spring and the engine is momentarily given more steam, which causes it to accelerate

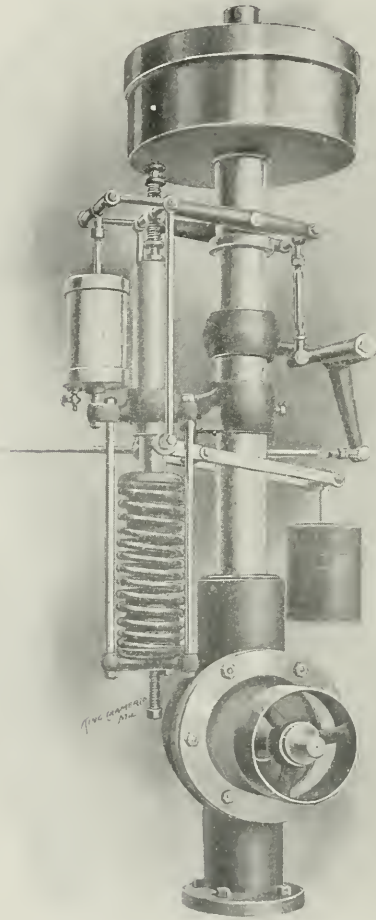


FIG. 208.—COMBINED PRESSURE AND SPEED REGULATOR.

its motion. The acceleration causes the governor to rise, and thereby shorten the cut-off, until it reaches such a height that it brings the cut-off gear back to about its original position, when the speed of the compressor will settle down to that cor-

responding to the new position of the governor. The reverse action takes place when the air pressure tends to rise. A perfectly constant air pressure can thus be maintained under all variations of the rate of consumption of air.

Other compressors of the Nordberg Company are illustrated in Figs. 209 to 214 and an intercooler in Fig. 215.

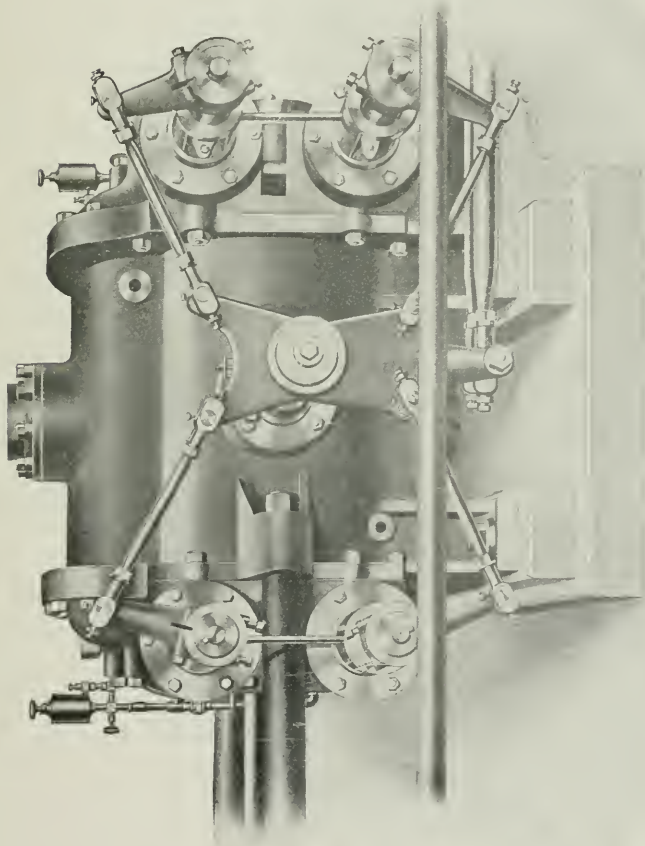


FIG. 209.—THE FULL-GEAR CORLISS AIR COMPRESSOR.

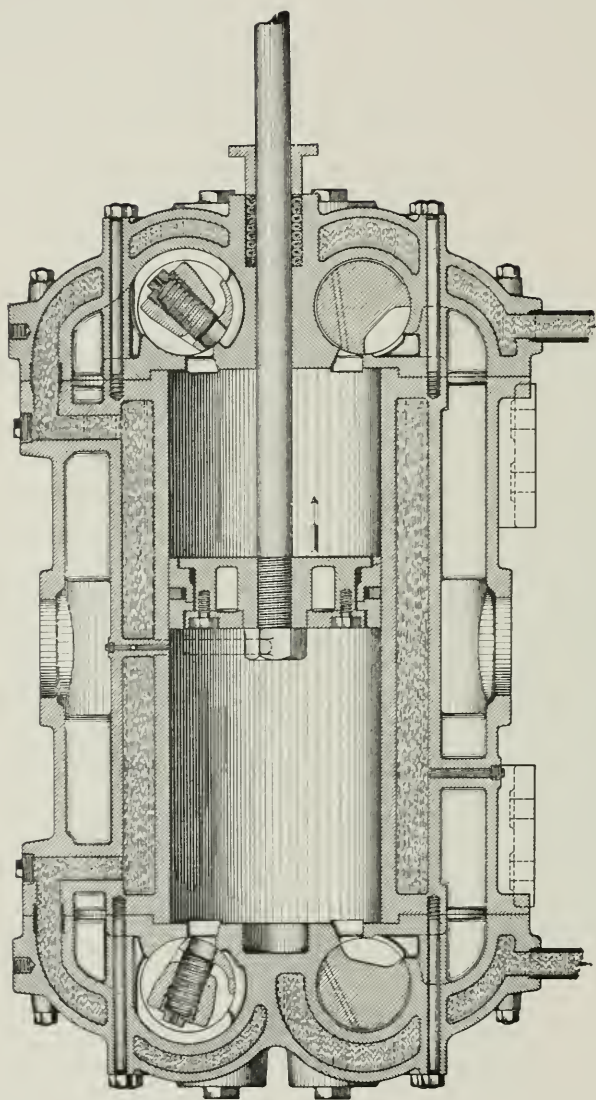


FIG. 210. SECTION OF CYLINDER FULL CORLISS VALVES.
With water-jacketed cylinder and heads.

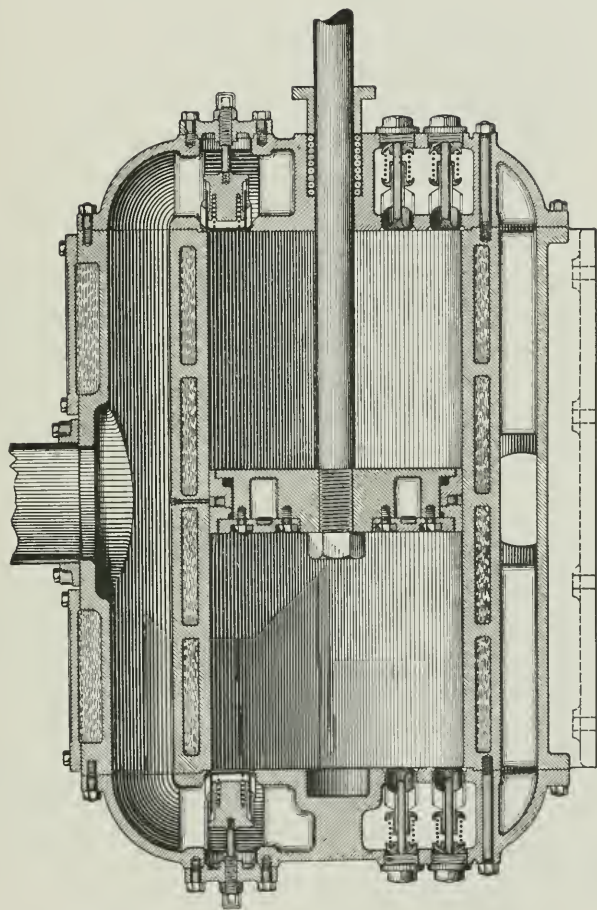


FIG. 211.—CYLINDER OF THE NORDBERG NATURAL GAS COMPRESSOR.
Inlet and discharge valves are in chambers in the cylinder heads covered with caps. Cylinder water-jacketed.

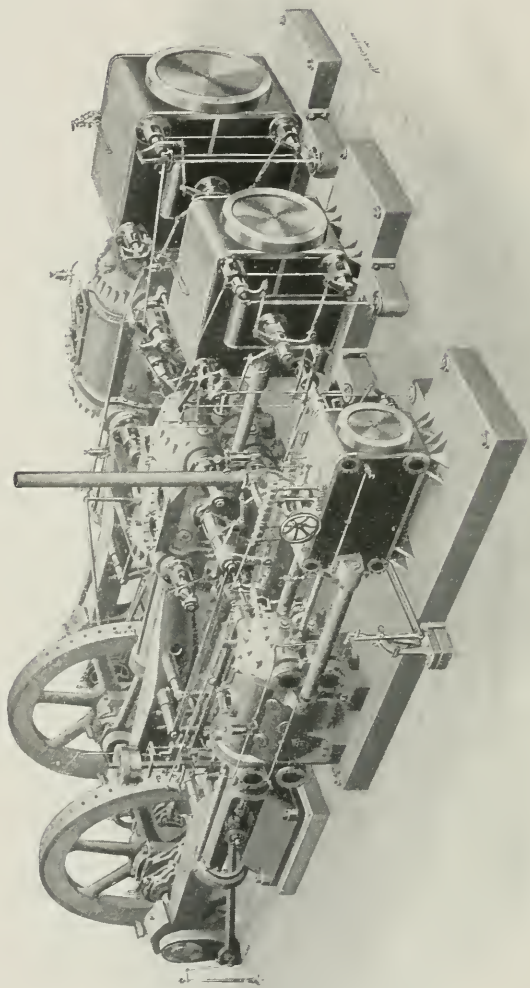


FIG. 212 THREE-STAGE TRIPLE EXPANSION NORDBERG AIR COMPRESSOR.

Indicated high pressure, 587. Steam pressure, 150 lbs. Free air compressed per minute, 3,878 cubic feet. 6½ cubic feet per horse power.

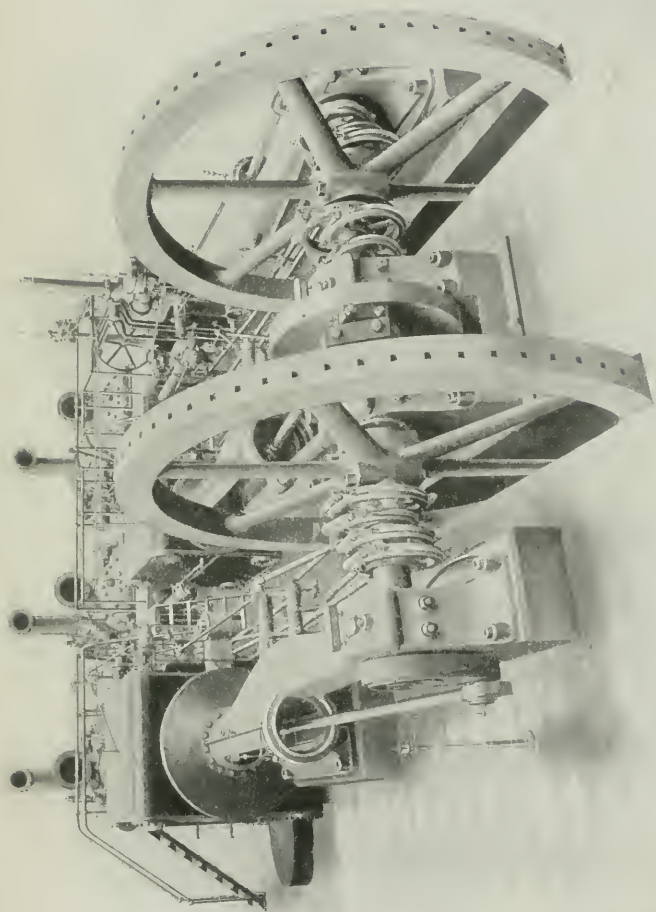


FIG. 213 — FRONT VIEW OF THREE-STAGE TRIPLE-EXPANSION AIR COMPRESSOR.
Built by the Nordberg Manufacturing Company for the Tamarack Mining Company, Calumet, Mich.

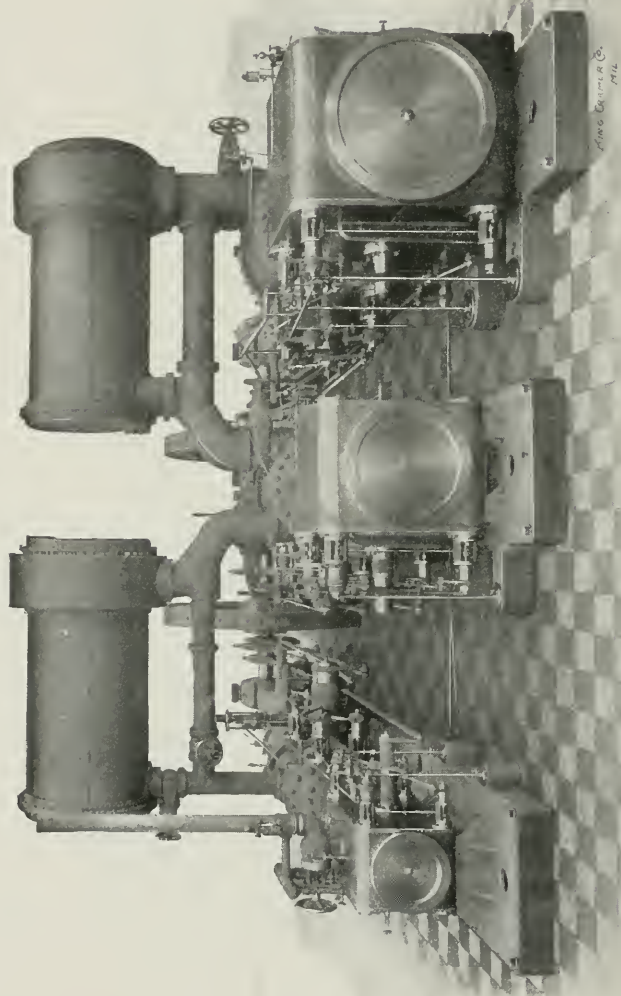


FIG. 214.—TRIPLE-EXPANSION, THREE-STAGE AIR COMPRESSOR.

With intercoolers. Nordberg Manufacturing Company, Milwaukee, Wis.

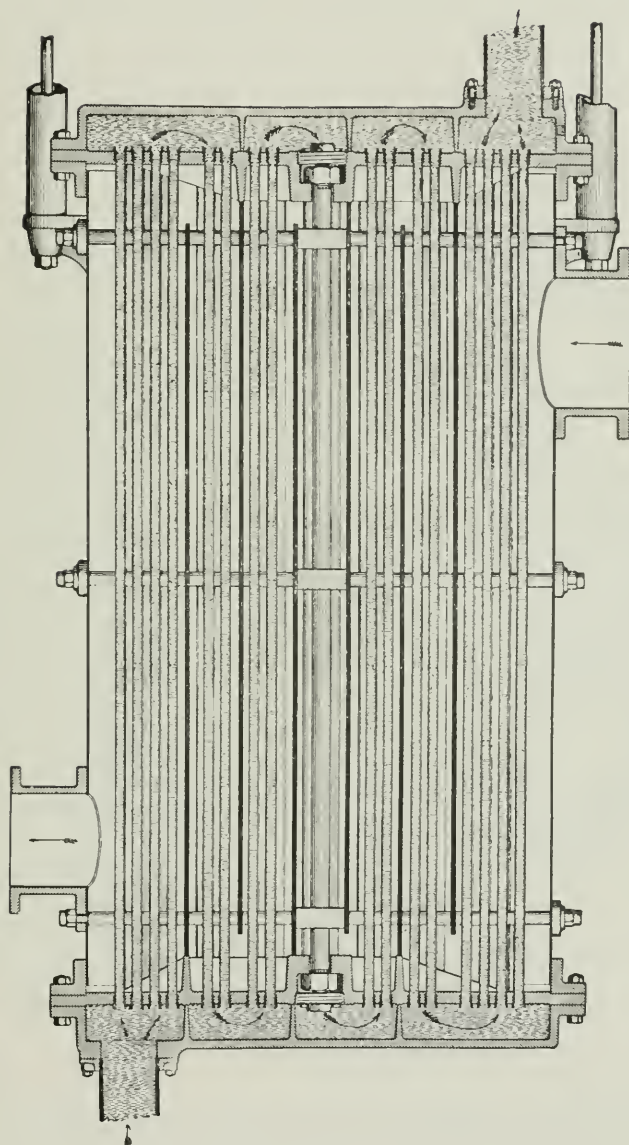


FIG. 215.—INTERCOOLER FOR MULTIPLE STAGE COMPRESSOR.
Nordberg Manufacturing Company, Milwaukee, Wis.

THE GAS AND GASOLINE ENGINE IN AIR COMPRESSION.

The field of usefulness of compressed air is already large, and is continually broadened by the increasing facilities for its production by simple means that may be easily transported to any

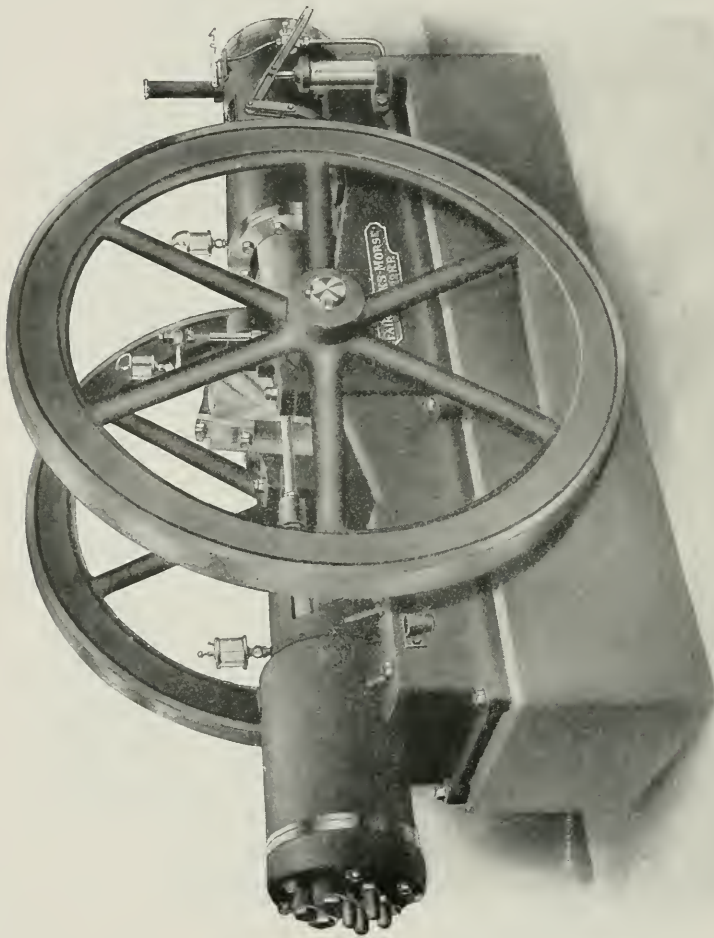


FIG. 216.—GASOLINE ENGINE-DRIVEN AIR COMPRESSOR.

needed location. This has been found in the adaptation of the gasoline engine for power and its combination with an air compressor. There is probably nothing so economical, within its limits of power, for compressing air as the gasoline engine; and certainly no means so easily transported to any required loca-

tion for temporary work. In the vast output of modern steel construction of buildings and bridge-work, compressed air now performs a vital portion of the work of assembling such structures, and has found its great aid in the portable air compressor

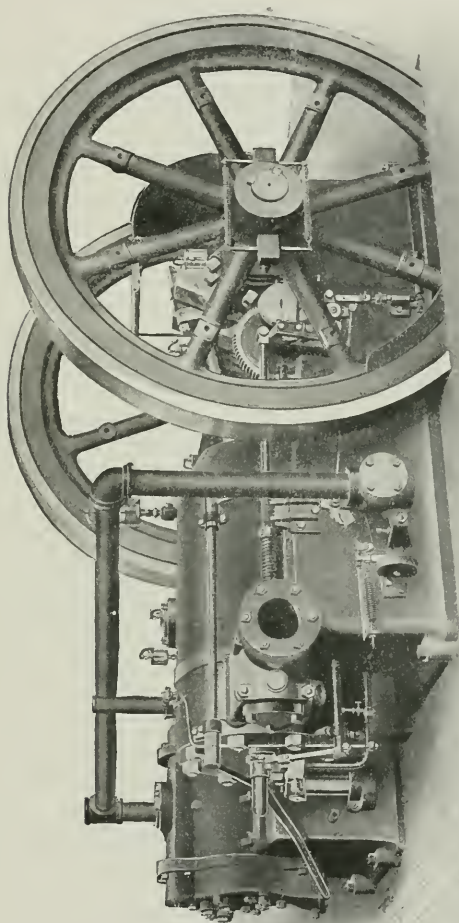


FIG. 217.—CROSS-CONNECTED, GASOLINE-ENGINE-DRIVEN AIR COMPRESSOR.
Gasoline-engine side. Fairbanks, Morse & Co., Chicago, Ill.

as a reliable power producer for operating air drills, hammers for riveting and chipping, and air lifts.

In Fig. 216 is illustrated the single-acting air compressor of the Fairbanks-Morse Company, with engine and air cylinders arranged in line and the pistons connected by a yoke and

rods. The engine is of the four-cycle type, with two fly-wheels heavy enough to carry the air piston over a second stroke.

Figs. 217 and 218 show the cross-connected double-acting air compressor and gasoline engine. The massive

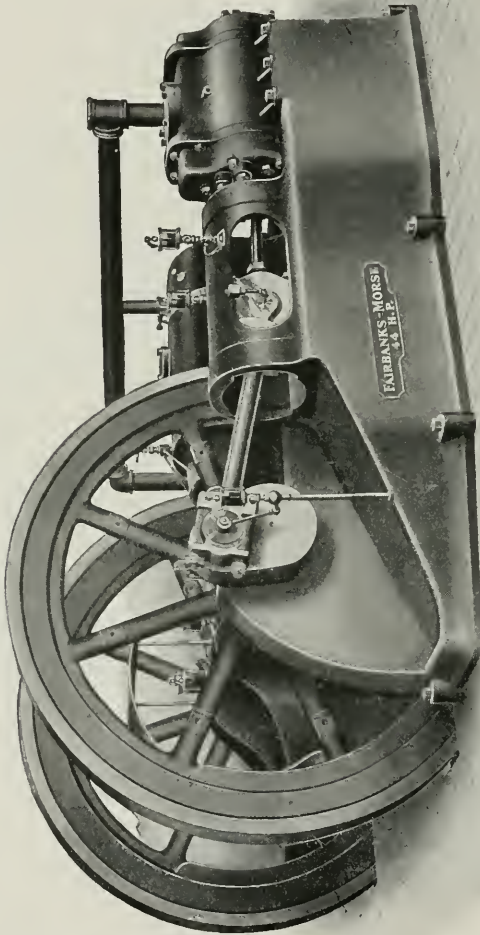


FIG. 218.—GASOLINE-ENGINE-DRIVEN AIR COMPRESSOR.
Compressor side. Double-acting air cylinder. Fairbanks, Morse & Co., Chicago, Ill.

frames of engine and compressor are strongly bolted together so as to make three rigid bearings for the crank shaft, which has a centre crank for the engine and an outboard crank for the compressor. The air valves are of the removable cage type

with seating springs. The engines are provided with electric and tube igniters, and a self-starting device with pump and gasoline charger, which is a most essential feature in a gasoline engine having a fixed load.

A KEROSENE-OIL COMPRESSOR.

The lines of economy are rapidly advancing in the devices for compressing air, and kerosene as a power fuel has come to

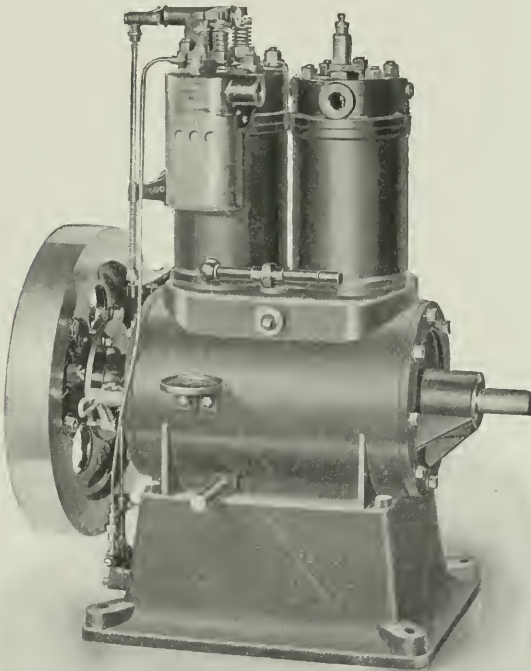


FIG. 219.—KEROSENE-OIL-ACTUATED AIR COMPRESSOR.

the front in the Merrill oil-actuated air compressor (Fig. 219), which is a self-contained and portable power, suited for all places in which a cheap and movable power is requisite, and well adapted for the operation of pneumatic tools on structural and bridge work. For the production of air power for oper-

ating pneumatic pumping systems it is the cheapest and most convenient power in use, save some special conditions of water power. These air pumps operating with kerosene oil use less than one pint of oil per horse power per hour. The oil is stored in the base of the engine, is supplied to the vaporizer by a small pump, and is vaporized by the heat of the exhaust. A blow lamp is used for starting the vaporizer.

COMBUSTION AND EXPLOSIONS IN COMPRESSOR CYLINDERS, RECEIVERS, AND PIPE LINES.

Ignition in compressor cylinders, receivers, and air pipes has been an occasional theme of discussion among engineers and operators of compressed-air plants, with sometimes misgivings in regard to its dangerous conditions. The danger has been over-rated, as it is well known that the explosive power of hydrocarbon vapor and air mixtures, even under the compression pressures, of gas and oil-vapor engines seldom exceeds 300 pounds per square inch. Such being the case, most air receivers have a limit of strength equal to this or more, so that as a precaution receivers that are used for pressures of any amount should have a tensile tested strength of at least five times the working pressure, and six times may be considered a safe test. As to the conditions of safety and danger, the following remarks from that valued journal, *Compressed Air*, are pertinent to the question in all its bearings:

“Compressed air claims to be and is a safe power. Occasionally we hear of a case of firing, which to some may appear to be a serious objection to the use of air; but if the causes are known and understood and due care is observed, firing becomes merely a matter of carelessness. . . . Compressed air is not inflammable, but during compression by mechanical means it is found advisable to use oil, and this oil, or the gases from it, are the sources of combustion. In most cases firing may be traced to the use of poor oil, but in others too much oil sometimes

causes ignition. It is a common mistake of engineers in charge of compressors to feed oil too rapidly to the air cylinder. It is simply necessary to supply oil enough to keep the interior of the cylinder and the moving parts moistened. Where steam is used there is a tendency to cut away the oil, hence engineers grow accustomed to feeding a larger supply than is required in an air cylinder. There is nothing to cut or absorb the oil in the air end; in fact, it is only after a considerable lapse of time that oil can get away when fed into the cylinder. There is no washing tendency as with steam, and a drop now and then is all that is required to keep the parts lubricated. Where too much oil is used there is a gradual accumulation of carbon, which interferes with the free movement of the valves and which chokes the passages, so that a high temperature may for a moment be formed and ignition follow. It is well to get the best oil, and to use but little of it.

“There are cases where firing has arisen from the introduction of kerosene or naphtha into the air cylinder for the purpose of cleaning the valves and cutting away the carbon deposits. Every engineer knows how easily he may clean his hands by washing them in kerosene; and as this oil is usually available, we have seen men introduce it into the air cylinder through a squirt-can at the inlet valve. This is a very effective way of cleaning valves and pipes, but it is a source of danger, and should be absolutely forbidden. High-grade lubricating oils are carefully freed of all traces of benzine, naphtha, kerosene, and other light and volatile distillates. The inflammability of the latter is so acute that it is a dangerous experiment to introduce anything of this kind into an air cylinder; and if any of our readers have had an explosion in a case where the engineer uses kerosene, it may be traced to this source. Closed inlet passages leading to the air cylinder through which the free air is drawn from outside the building have many advantages, but one seldom thought of is that they interfere with the tendency of the engineer to squirt kerosene into the cylinder.

"Soft-soap and water is the best cleanser for the air cylinder, and it is recommended even in cases where the best oil is used. Long service will result in more or less accumulation of carbon; hence it is advised that engineers, once or twice a week or oftener if necessary, fill the oil cup with soft-soap and water and feed it into the cylinder as the oil is fed.

"Ignition in compressed-air discharge pipes and passages is not uncommon. At times this ignition is in the nature of an explosion. Two air receivers were blown up during the construction of the New York Aqueduct; in one case the engine room was destroyed by fire resulting from this explosion. We have also records of two other cases where spontaneous explosions in the air receiver have resulted in the destruction of the engine room by fire. Other instances occur where ignition takes place near the air compressor, the pipes becoming red-hot at the joints. This ignition has been known to extend into the air receiver, and in one instance the flames were carried down into the mine by the compressed air.

"In all such cases large volumes of compressed air were used. It is plain that the cause of the explosion or ignition is an increase of temperature above the flash point of the oil which is used to lubricate the compressor. A thick or cheap grade of cylinder oil should never be used in an air compressor. Thin oil which has a high flash point, and which is as free from carbon as conditions of lubrication will admit, is the best oil. A correspondent calls attention to explosions where the flash point of the oil is 554° F., and ignition point 606° F. We know of an instance where ignition took place with oil which had a flash point of 575° F., ignition point 625° F. Conditions were similar to those mentioned by our correspondent, that is, the air was compressed to about 60 pounds per square inch gauge pressure. If the temperature of the air before admission to the compressor is 60° F., and it is compressed to 58.8 pounds gauge pressure, the final temperature, where no cooling is used during compression, will be 369.4° F., or a total increase

of 309.4° . If air is admitted at 60° F., is compressed without cooling to 73.5 pounds gauge pressure, the final temperature will be 414.5° F., and the total increase of temperature 354.5° . Under such circumstances the question naturally arises, How is it possible when using oil with an ignition point of over 600° to get an ignition, especially as water jackets and other methods of cooling are used which should reduce the final temperature? The figures are also based on dry air, which increases in temperature during compression to a greater degree than moist air, and it is known that air that is used in compressors is never very dry. The theoretical figures show that in order to get ignition with the oil mentioned, the gauge pressure should be about 200 pounds per square inch, where no cooling takes place.

"It is plain that there must be an increase of temperature or ignition would not take place. This increase of temperature may result either from an increase of pressure which is not recorded on the gauge, or there may be an increase of temperature without a corresponding increase of pressure. Take the first instance, and it is not difficult to understand that an air compressor might deposit carbon from the oil in the discharge passages or discharge pipes which in the course of time will accumulate and constrict the passages so that they do not freely pass the volume of air delivered by the compressor, hence a momentary increase of pressure might exist in the cylinder heads or in the discharge pipe which leads from the air cylinder to the receiver; this momentary increase of pressure would surely carry with it an increase of temperature which might exceed the ignition point of the oil. A badly designed compressor with inefficient discharge passages might produce this trouble. Too small a discharge pipe or too many angles in discharge pipes might also tend to produce explosions. But we have known instances where ignition has occurred in a well-designed system, hence we must look for other causes. In our judgment the majority of cases may be traced to an increase of temperature without an increase of pressure; this increase of

temperature can be excessive only when the temperature of the incoming air is excessive. A hot engine-room from which air is drawn into the cylinder is a bad condition. We have known cases where the incoming air was drawn from the neighborhood of the boiler, the temperature being close to 150° F. This means, of course, that if the total increase of temperature when air is compressed to 73.5 pounds gauge pressure is 354.5° , the temperature of the initial air should be added to this figure, and that the final temperature might be 504.5° .

"But we have known ignition to take place when the temperature of the incoming air was normal, when the discharge passages and pipes were free and of ample area, hence we must look for some other cause. The only possible explanation is that the temperature of the incoming air is made excessive by the sticking of one or more of the discharge valves, thus letting some of the hot compressed air back into the cylinder to influence the temperature before compression. When a piston of an air compressor has forced a cylinder volume of air through the discharge valve, and when this piston has its direction of movement reversed, there will immediately be a tendency of the air just compressed and discharged to return to the cylinder. In this it is checked by the discharge valve, but through long and constant use these discharge valves become encrusted with carbon and are not free to move, hence there may be a moment when one of these valves sticks, or it may not seat properly; in either case there will be some hot compressed air in the cylinder when the piston starts on its return stroke of compression; the air may have lost its pressure, but not its temperature, and it is not difficult to understand a leaky discharge valve letting enough air back into the cylinder to increase the initial temperature to two or three hundred degrees. If so, and we are compressing air to 73.5 pounds gauge pressure, we have say 300° temperature in the free air before compression, and as the increase is 354.5° , the resulting temperature might be 654.5° .

“As a remedy we would suggest more care in selecting the best air compressor and in frequent cleaning of the discharge valves and passages. The best air compressors are built so that the discharge valves may be readily removed; these valves should be cleaned regularly once a week by the engineer, who should make sure that they fit properly. It is impossible to get good lubricating oil that is free from carbon, hence there will always be more or less carbon deposited on the discharge valves, but this must not be allowed to accumulate.

“Intercoolers between air cylinders and after-coolers between final cylinder and receiver are also recommended. The best intercoolers are made of nests of brass tubes, the air passing around the tubes and the water through them, hence there is a thorough splitting up of the air and efficient cooling. One of these coolers located in the discharge pipe will absolutely prevent the passage of flame and will insure the protection of the mine against fire even though there be ignition at or near the air cylinder.”

Chapter XXII.

COMPRESSED AIR IN MINING AND QUARRYING

COMPRESSED AIR IN MINING AND QUARRYING.

THE rock drill as a self-acting power machine for rock-drilling is the outcome of the past half-century; the first self-operating percussion rock drill dates from 1849, under the Couch patent; since which time Fowle, Burleigh, Ingersoll, Wood, Githens, Rand, and Sergeant have improved on its design and brought its construction to the present perfect action. At this time more than a hundred thousand rock drills attest their usefulness in mining, tunnelling, and quarrying throughout the civilized world.

Fig. 221 is a section of the Ingersoll drill. *A*, the shell; *B*, piston with rotating device; *R*, air chest; *T*, bolt that holds the heads of the air chest and on which the balanced piston valve slides, and which is thrown by small air ports opened by the drill piston at the end of its stroke.

Other models of drill valves are made by the Ingersoll-Sergeant Drill Company, the invention of Mr. Henry C. Sergeant, among which are the tappet valve for a rock drill. The

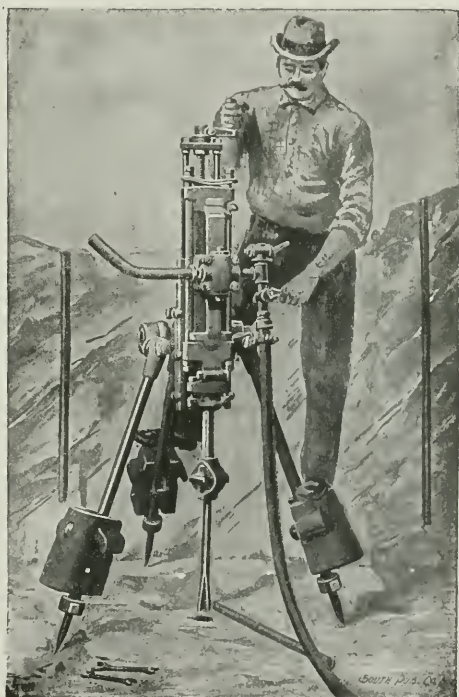


FIG. 220.—THE NEW INGERSOLL.
On universal tripod.

ports are radial and flat, and are opened and closed by the swing of the valve on its centre. The valve is thrown by the shoulders on the piston striking the valve arms.

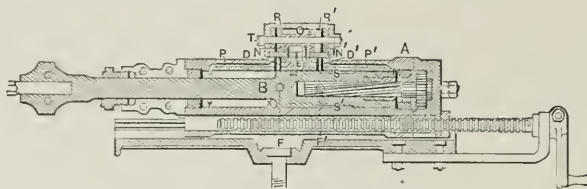


FIG. 221.—SECTION OF THE INGERSOLL.

Another improvement is shown in Fig. 223, being an arc tappet valve motion, for a rock drill. The valve is moved on a circle radial with the tappet centre, and is thrown by the tappet-arm contact with the shoulders on the piston.

Another rock drill of this company is the "Sergeant drill," having a piston valve as in the Ingersoll model, which is thrown

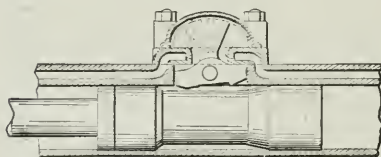


FIG. 222.—TAPPET VALVE.

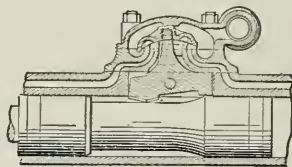


FIG. 223.—ARC TAPPET VALVE.

by an auxiliary arc valve or ported sector that opens the small ports alternately behind the piston valve. The sector is thrown by contact with the shoulders of the central recess in the drill piston. It is the trigger of the main or piston valve, and opens or closes the air passages to the piston valve alternately. It is

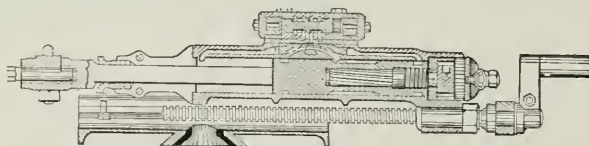


FIG. 224.—AUXILIARY ARC VALVE.

so light that it is quickly and positively moved by the passing of the piston shoulder and held in position to near the end of the drill piston stroke.

TYPES OF AIR AND STEAM ROCK DRILLS OF THE INGERSOLL-SERGEANT DRILL CO.



FIG. 225.—THE SERGEANT ROCK DRILL.

In sizes 2, $2\frac{3}{4}$, 3, $3\frac{1}{4}$, and $3\frac{1}{2}$ -inch diameter of pistons. Stroke, $4\frac{1}{2}$, $6\frac{1}{2}$, and 7 inch.

TYPES OF AIR AND STEAM ROCK DRILLS OF THE INGERSOLL-
SERGEANT DRILL CO.



FIG. 226.—THE INGERSOLL ECLIPSE DRILL.

Mounted on Sergeant universal joint tripod. $1\frac{3}{4}$, $2\frac{1}{2}$, $2\frac{3}{4}$, 3, $3\frac{3}{8}$, $3\frac{1}{2}$, $4\frac{1}{4}$, and 5-inch diameter of piston. 4 to 8-inch stroke.

TYPES OF AIR AND STEAM ROCK DRILLS OF THE INGERSOLL-SERGEANT DRILL CO.

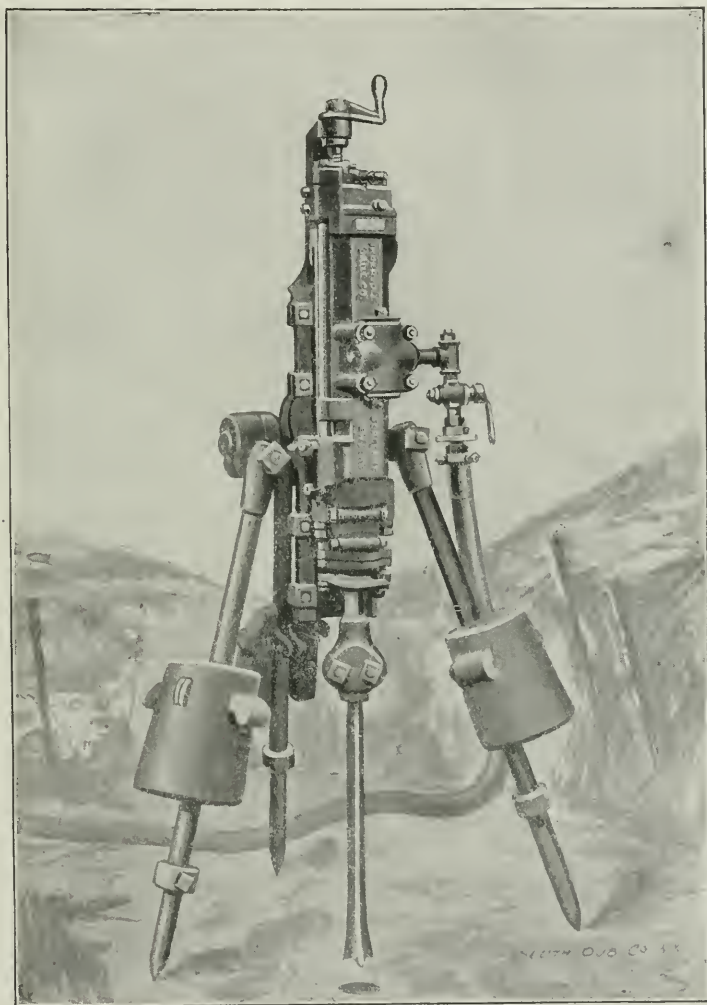


FIG. 227.—THE INGERSOLL AUTOMATIC FEED DRILL.

As the piston approaches the front head in cutting, it strikes a knuckle joint which turns a nut on the feed screw. The largest rock drill made; $4\frac{1}{2}$ and 5-inch diameter; 8-inch stroke. Its special application is in submarine work.

TYPES OF AIR AND STEAM ROCK DRILLS OF THE INGERSOLL-SERGEANT DRILL CO.

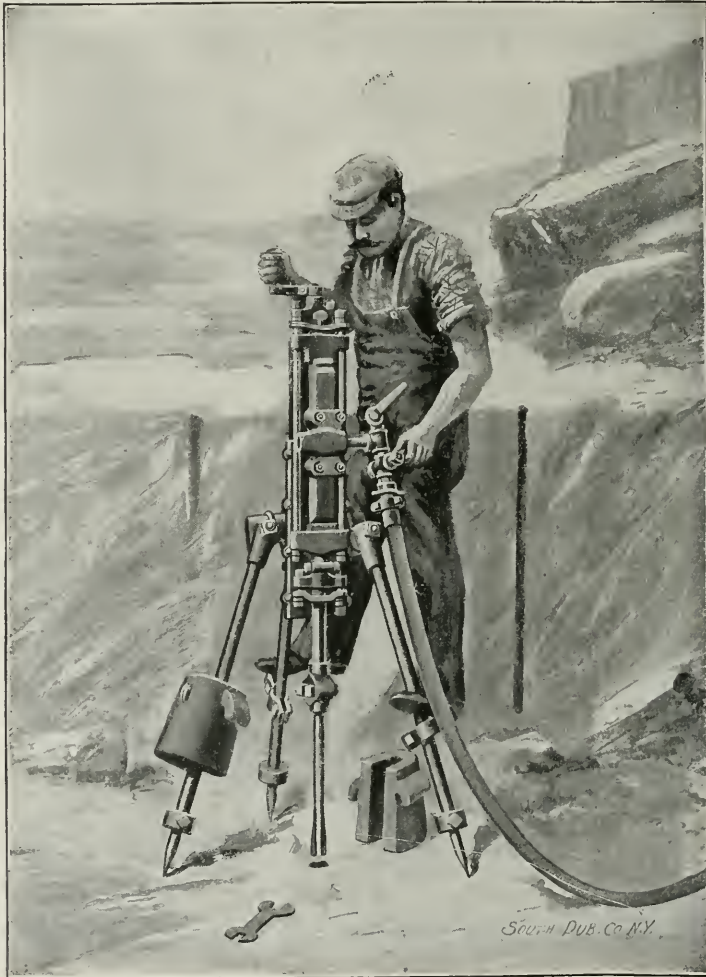


FIG. 228.—THE ARC VALVE TAPPET DRILL.

A positive valve motion by direct contact of the tappet with the piston. Made in the usual sizes of the Ingersoll-Sergeant Drill Company.

THE BAR CHANNER.

In the bar channeller has been found one of the most useful of the air-driven machines for quarrying dimension stone for building. It has been greatly developed and improved of late years. One of its novelties is an independent air motor that traverses the drill forward and back along the bars at regulated

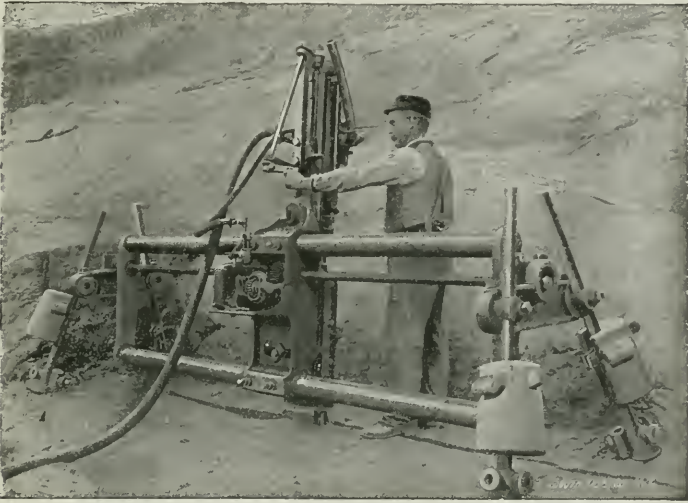


FIG. 229.—THE CHANNELLING MACHINE.

speed, thus enabling long channel cuts to be made quickly and with accuracy. This with the quarry bar and gadder are essential features in the operation of marble and slate quarries.

COAL CUTTING BY COMPRESSED AIR.

The past decade has developed great progress in the mining of coal in Europe and the United States, by the introduction of compressed air for many of the operations that before were tediously wrought by hand. The hand coal pick has been largely displaced by the introduction of the compressed air pick or coal-cutting machine, which is essentially a rock drill on wheels with a long sharp blade, by which the wall face of a coal seam is under-cut along the bottom of its face and shear-

cut in vertical seams from top to bottom by merely changing the small wheels to larger ones to give the pick a vertical

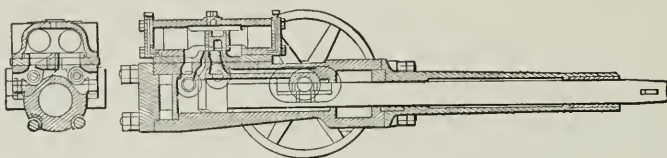


FIG. 230.—COMPRESSED AIR COAL-CUTTING MACHINE.

range. By the use of the coal-cutter a miner's work per shift is increased from four to six times over old methods.

Fig. 230 is a sectional view of the Ingersoll-Sergeant Coal-Cutting Machine with its double piston valve movement in which the alternating strokes of the valves are made automatic by the cross connections of their ports, thus alternating the stroke of the main pick piston.

Fig. 231 shows the position of the coal-cutter on an inclined

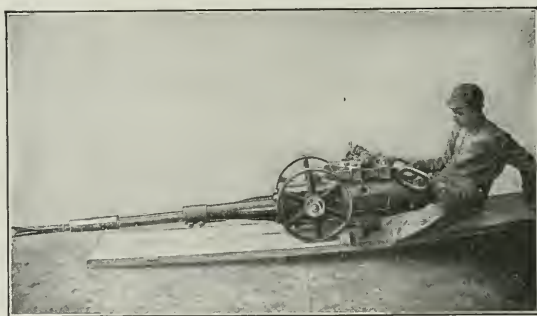


FIG. 231.—INGERSOLL-SERGEANT COAL-CUTTER.

platform and the position of the operator ready for making an under-cut in a coal face.

COMPRESSED AIR FOR INGERSOLL-SERGEANT ROCK DRILLS AND COAL-CUTTERS.

The following table is intended to show at a glance the approximate quantity or volume of free air required for operating rock drills and coal-cutters, the air being delivered to the machines at 60 pounds pressure.

As applied to rock drills, these figures are necessarily approximate only, owing to the varying conditions under which such work is performed; but they will be found to apply closely to average conditions in rock of moderate hardness. A liberal allowance has been made above the actual requirements of new machines, to provide for wear, etc., but no allowance is made for leaky pipe, as this should not be permitted to exist. In soft material the actual drilling time is short, and more drills can be run with a given size compressor than where the mate-

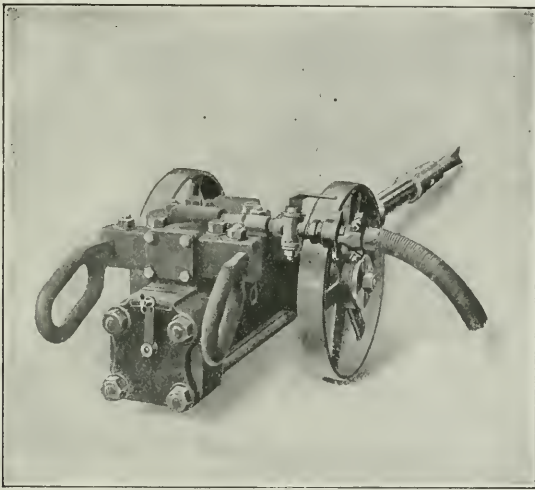


FIG. 232.—REAR VIEW, COAL-CUTTER.

rial is hard and the drills running continuously for a longer period.

In tunnel work in hard rock, where a high air pressure is carried to insure rapid progress, experienced contractors have found it profitable to provide compressor capacity in excess of the usual requirements by 25 to 50 per cent.

For coal-cutters, the figures given are liberal, and more machines can probably be added where a large plant is in operation; but it should always be remembered that it is better economy to provide a large compressor and run it slowly, rather than a small one that has to be driven to its full capacity. This

fact is recognized by the best engineers, and it applies more particularly to a compressor than to an engine or boiler.

The capacities in this table are based on 60 pounds air pressure; if 75 pounds is used, one-fifth more volume should be added to the volume stated in the table; if 90 pounds, two-fifths should be added.

TABLE XL.—CUBIC FEET OF FREE AIR PER MINUTE REQUIRED TO RUN FROM ONE TO FORTY INGERSOLL-SERGEANT DRILLS WITH SIXTY POUNDS PRESSURE.

Number of machines.	ROCK DRILLS—SIZES.								COAL CUTTERS.	
	A 2 inch.	B 2½ inch.	C 2¾ inch.	D 3 inch.	E 3¼ inch.	F 3½ inch.	G 4¼ inch.	H 5 inch.	¾ inch.	1 inch.
1	65	70	95	110	115	125	140	165	70	93
2	110	120	160	190	200	230	250	280	140	186
3	156	174	234	279	294	333	360	405	210	279
4	196	220	304	356	372	428	460	524	280	372
5	230	260	370	425	445	510	555	635	350	465
6	264	294	426	486	516	588	642	738	420	558
7	294	329	476	546	581	658	721	826	490	651
8	320	360	520	600	640	720	800	920	560	744
9	360	405	585	675	720	810	900	1,035	630	837
10	400	450	650	750	800	900	1,000	1,150	700	930
12	480	540	780	900	960	1,080	1,200	1,380	840	1,116
15	....	675	975	1,125	1,200	1,350	1,500	1,725	1,050	1,395
20	....	....	1,300	1,500	1,600	1,800	2,000	2,300	1,400	1,860
25	....	....	1,625	1,875	2,000	2,250	2,500	2,775	1,750	2,325
30	....	....	1,950	2,250	2,400	2,700	3,000	3,450	2,100	2,790
40	....	....	2,600	3,000	3,200	3,600	4,000	4,600	2,800	3,720

The operation of the compressed-air coal cutter depends upon the automatic action of a double piston valve in a valve chest immediately over the cylinder. The action of the valve pistons is alternating, each piston opening ports for its opposite valve, one of which is the supplementary piston.

The illustrations will serve to give a correct idea of the appearance of the pick machine. It is mounted on wheels 16 to 20 inches in diameter, according to the requirements; weighs from 500 to 750 pounds, and is easily moved from one place to another, the time consumed in moving from room to room of average length, including loading and unloading, being about ten minutes. In operation the machine is placed on a platform made of 2-inch pine, about 8 feet long and 3 feet wide, which

is so inclined toward the face by means of a trestle under the outer end that the recoil of the machine is neutralized by gravity and feeds down to the coal. The method of mining is as

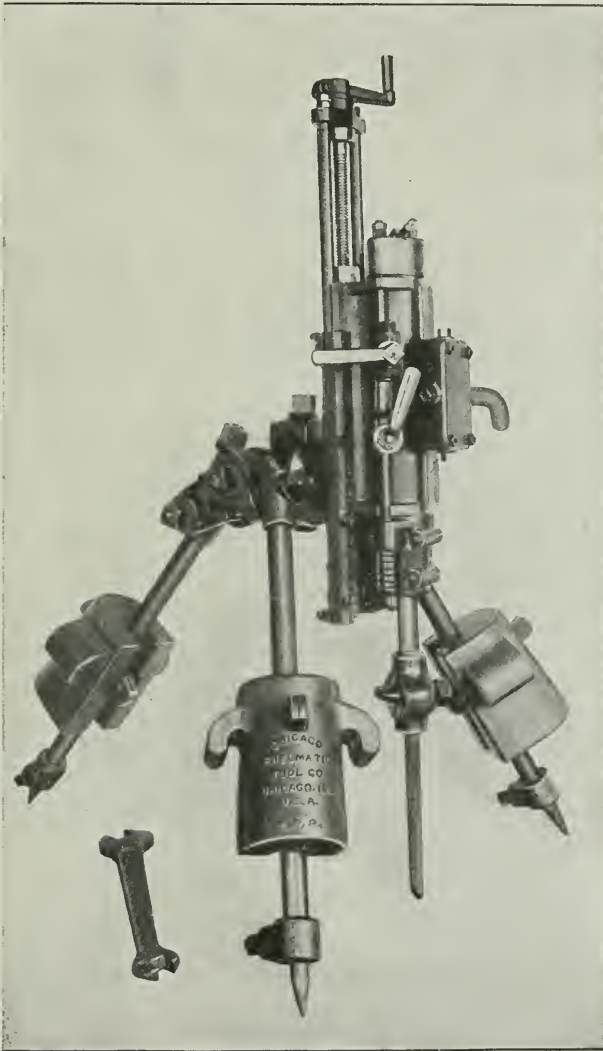


FIG. 233.—THE CHICAGO ROCK DRILL.

The Chicago Pneumatic Tool Co., Chicago, Ill., and New York City.

follows: The runner sits on the platform behind the machine, which he holds by the handles; the pick is shot against the coal by means of compressed air at a pressure of from 40 to 90

pounds, striking with a force and speed which can readily be adjusted to range from 160 to 250 blows per minute, at a force per blow at from 5 to 1,500 pounds. The runner uses a block attached to his shoe by a strap to chock the wheels of the machine against the recoil.

ROCK DRILLS OF THE CHICAGO PNEUMATIC TOOL COMPANY.

The Chicago reciprocating rock drill is an improvement on the old style rock drill; it is equipped with an auxiliary valve,

which acts as a controller for the main valve, thus insuring a perfect valve movement. It is used in quarries, for excavating and tunnelling, and in shaft and mine work.

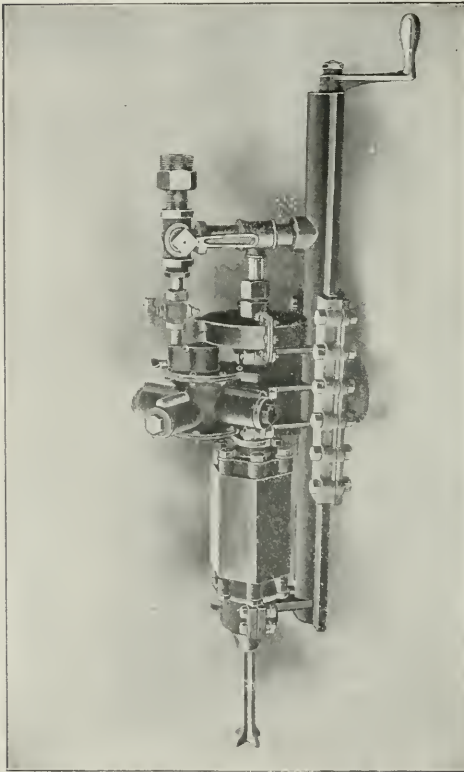


FIG. 234.—CHICAGO ROCK DRILL.
Hammer type.

The Chicago rock drill is a combination of a pneumatic hammer and a pneumatic drill. In the cylinder of the hammer is set a drill bit made of grooved steel $\frac{7}{8}$ inch in diameter, in any desired length. The chuck is cut out to fit a cross-section of the drill bit, so that the same can be set in the hammer socket loosely, requiring no set screws, bolts, or pins to hold it in place. This

saves much time and annoyance. A tube encases the drill bit, the tube encircled by a spiral, which, when the drill bit revolves,

serves to remove from the hole, as the drill advances, all the cuttings of rock and other material, much after the order of the auger bit. There are four tongues riveted to the internal diameter of the casing, fitting four grooves in the bit, compelling it to rotate simultaneously with the drill.



FIG. 235.—NO. 2½ DRILL ON TRIPOD.

ROCK DRILLS OF THE MCKIERNAN DRILL COMPANY,
NEW YORK CITY.

The drills of this company are made in nine sizes. viz.: 2 in., 2½ in., 2¾ in., 3 in., 3⅛ in., 3¼ in., 3½ in., 3⅝ in., and 5 in.; the last size being a specially arranged drill for submarine drilling.

They are substantially constructed on the lines of the expired Ingersoll patents, with the usual spiral bar with ratchet and pawl rotation, and provided with a release movement for obviating possibility of breakage. The cylinder heads are held by strong helical springs of steel braced by through rods to lugs at the lower end of the cylinder, thus relieving the machine from jar by the piston striking the cylinder head.

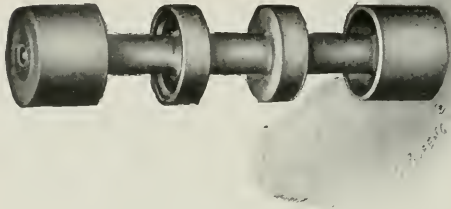


FIG. 236.—THE PISTON VALVE.

One of the essential features of this rock drill is the valve, on which depends the action of the drill. The valve as shown in the cut is of a four-part piston type, turned from solid tool steel, has a perfectly balanced motion and moves automatically, having no mechanical connection with the piston; it being operated by air ports opened and closed by the alternating movement of the drill piston. An annular recess at the central part of the piston opens an air port for pressure and exhaust at the ends of the piston valve. The air pressure in the valve chest is between each of the ends and central discs of the valve, while the exhaust takes place between the central discs. Thus the valve is perfectly balanced and only requires its friction to be overcome by the alternating air pressure on the ends.

The submarine air or steam rock drill of this company has a cylinder of 5-inch diameter, $8\frac{1}{2}$ -inch stroke, and for the purpose of submarine drilling is mounted upon a wooden slide or a special frame to give it a long reach. The whole apparatus is mounted on a spud platform, or a heavy scow, and sometimes both when the boiler and air compressor are carried on the scow. In this way the drill has a more steady position on the spud frame, and is readily moved to new positions.

ROCK DRILLS OF THE PHILLIPS ROCK DRILL COMPANY,
PHILADELPHIA, PA.

The "Badger" drill is the trade name of the rock drills made by this company. The "New Badger" is their latest improvement.

Its general construction follows the lines of the best types. The blow of the drill is uncushioned, and all the energy put into the piston, less that due to the friction of the parts, is expended at the cutting edge of the bit. The valve is of the spool or piston type, operated by air ports at each end alternately opened by the recess in the drill piston near the ends of its stroke.

In Fig. 239 is shown the "New Badger" drill on tripod

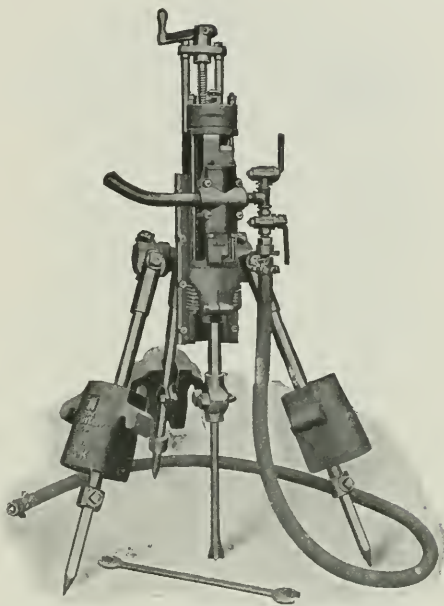


FIG. 237.—THE BADGER DRILL.

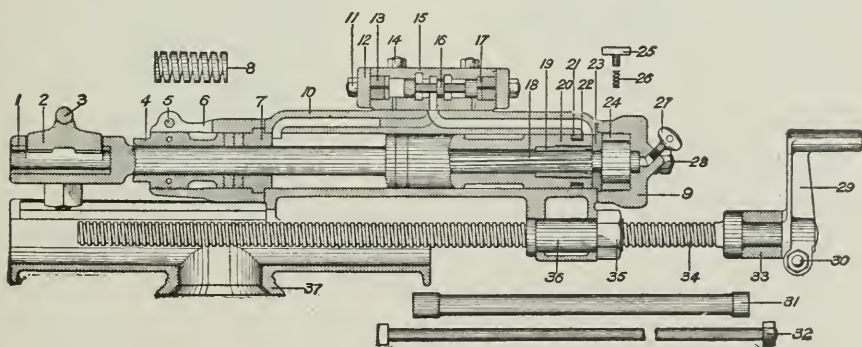


FIG. 238.—LONGITUDINAL SECTION OF THE DRILL.

Showing the figured parts which are named in their catalogue.

working close to the side face of a rock wall, one of the most inconvenient positions for operating a rock drill.

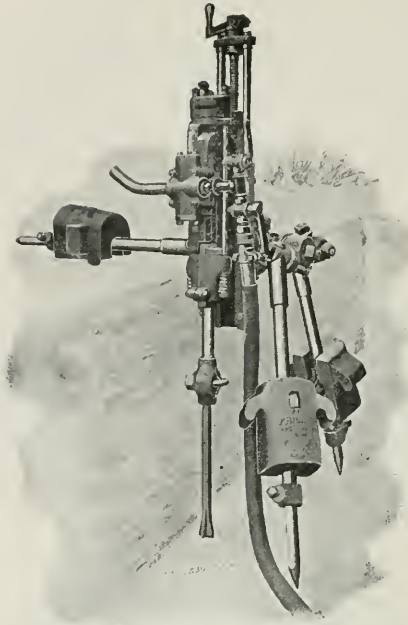


FIG. 239.—THE "NEW BADGER."

Working close to side face.

THE NEW LEYNER COMPRESSED-AIR
ROCK DRILL. J. GEORGE LEYNER,
DENVER, COLO.

This is a pneumatic or air drill, for drilling rock or ore in mines, tunnels, and quarries. It is unlike the type of rock drills that have been in use for nearly forty years, especially in this, that the steel is entirely disconnected from the piston. That is to say, the steel, instead of being plunged by the piston against the rock, is struck by the piston and driven into the rock.

A hardened steel tapered pin in the front end of the piston

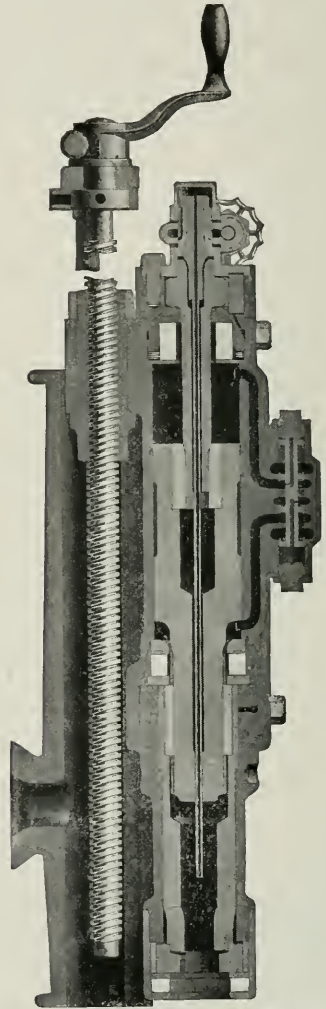


FIG. 240.—SECTION OF THE LEYNER
ROCK DRILL.

strikes the hardened end of the shank of the drill steel. The weight of the piston is but a little more than one-fourth of the weight of the piston of an ordinary drill, but its velocity is about four times as great.

The steels used for drilling are hollow. A small steel tank is filled with water and connected to the air line to obtain pressure to carry the water to and through the drill. This tank is connected by means of a hose to a suitable connection on the back of the machine. A steel tube passes from this water connection through the machine and into the hollow drilling steel.

A needle valve fitted to the machine gives the operator perfect control of the water supply.

Through a valve in front of the chest air is admitted into the front of the cylinder, passes out through the steel, and is discharged from the bit into the hole being drilled, thus expelling the cuttings. By turning the water valve, the operator mingles a spray of water with the compressed air, so that the cuttings expelled from the hole are free from dust.

The Leyner drill is made in two sizes, viz.: $2\frac{1}{2}$ -inch diameter of piston, whole weight of drill 115 pounds; 3-inch diame-

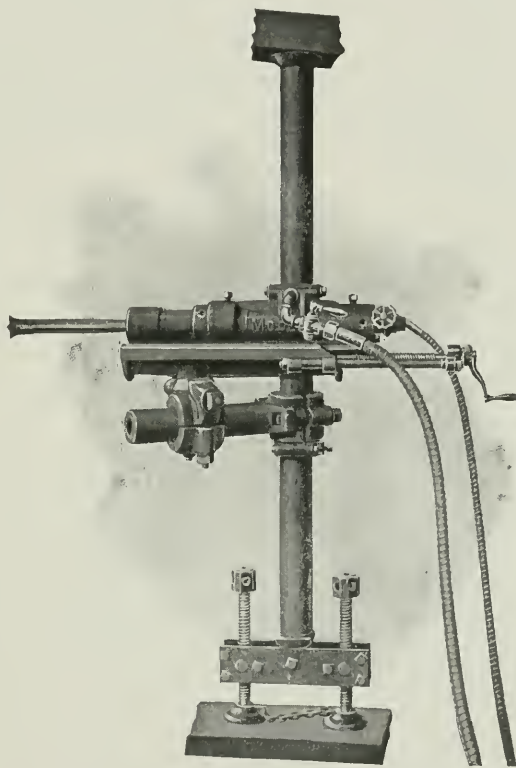


FIG. 241.—LEYNER ROCK DRILL ON COLUMN.

ter of piston, whole weight 165 pounds; ready for mounting on tripod or column.

ROCK DRILLS OF THE RAND DRILL COMPANY, NEW YORK CITY.

Fig. 242 represents the general form of the little Giant Rock drill, and Fig. 243 the detail of the valve gear and rotating device in section.

The valve of the Little Giant drill is a plain slide-valve, al-

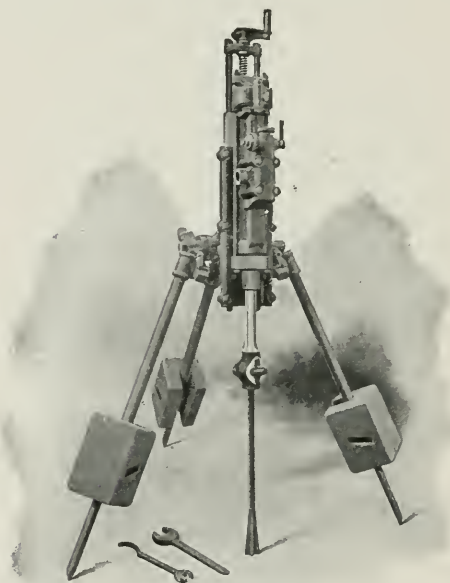


FIG. 242.—THE LITTLE GIANT ROCK DRILL.

ways thrown in the same direction in which the piston is moving. The opening and closing is effected in a positive manner.

A three-arm rocker, or lever, operates the valve and is held in place by a pin; the rocker is placed in a recess of the cylinder, between the ends of a double-headed piston, and its upper arm, or head, engages into the valve; as the piston reciprocates

it shoves the rocker in the direction in which it is going and thus moves the valve with it.

Fig. 244 represents the piston or spool valve of the Slugger air drill. It is a three-part spool, and is operated by the opening and closing of small ports at the terminal strokes of the drill piston, and is stopped by steel spools abutting against soft elastic buffers.

The Slugger drill is made in five sizes from $2\frac{3}{4}$ to $3\frac{5}{8}$ inch diameter, and from $6\frac{1}{4}$ to $7\frac{3}{4}$ inch stroke. These drills have

the delayed action of the valve at the striking end of the stroke, whereby the air or steam is not admitted to the front of the piston until the blow is struck. The compressed air and steam rock drills are essentially alike in action and have a good record in mining, tunnelling, and quarry work.

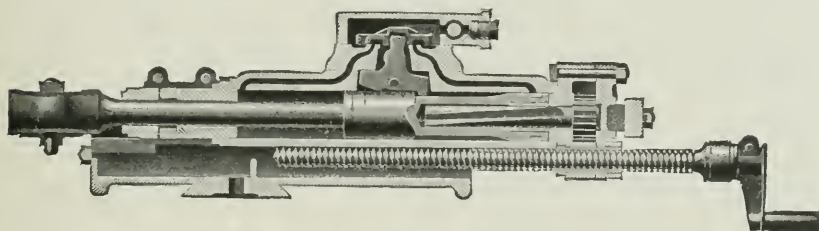


FIG. 243.—VALVE GEAR AND ROTATING DEVICE
Of the Little Giant rock drill.

We give herewith a table of cubic feet of free air per minute required to operate from one to fifty Rand drills, of various sizes, at 60 pounds pressure at sea level and run under average mining conditions:

TABLE XLI.—AIR REQUIRED TO OPERATE RAND ROCK DRILLS.

Number or name.	Kid.	No. 1.	No. 2.	No. 3.		No. 3¼.	No. 4.	No. 5.	No. 7.
Diam. of cylinder, in inches.	$1\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{3}{4}$	$3\frac{1}{8}$	$3\frac{3}{16}$	$3\frac{1}{4}$	$3\frac{5}{8}$	$4\frac{1}{2}$	$5\frac{1}{2}$
Number of drills.									
1	35	53	64	95	....	103	112	132	154
2	61	93	112	166	....	180	196	231	270
3	88	133	160	238	....	258	280	330	385
4	113	170	206	306	....	332	360	425	495
5	135	204	246	365	....	396	430	508	592
6	158	238	288	428	....	463	505	595	693
7	185	280	340	504	....	545	593	700	815
8	210	318	384	580	....	620	672	792	924
9	231	350	423	626	....	680	740	870	1,015
10	256	387	466	693	....	750	817	964	1,122
12 .....	....	460	554	822	....	890	970	1,140	1,330
15 .....	....	573	691	1,030	....	1,112	1,210	1,425	1,665
20 .....	....	756	914	1,350	....	1,470	1,600	1,880	2,200
25 .....	....	930	1,120	1,665	....	1,800	1,960	2,310	2,700
30 .....	....	1,112	1,343	2,000	....	2,163	2,355	2,780	3,240
40 .....	....	1,482	1,790	2,660	....	2,880	3,140	3,700	4,310
50 .....	....	1,855	2,240	3,325	....	3,600	3,920	4,620	5,400

Following is an appendix to above table giving factor for determining free air per minute required at 60, 70, 80, 90, and

100 pounds pressure, and for altitudes from sea level to 10,000 feet above:

Altitude in feet above sea level.	Atmospheric pressure, pounds per square inch.	FACTOR OF MULTIPLICATION.				
		Pressure at Drill.				
		60 pounds.	70 pounds.	80 pounds.	90 pounds.	100 pounds.
....	14.7	1.00	1.133	1.26	1.40	1.535
500	14.45	1.015	1.15	1.28	1.425	1.563
1,000	14.12	1.03	1.17	1.31	1.45	1.59
1,500	13.92	1.048	1.19	1.33	1.48	1.62
2,000	13.61	1.06	1.21	1.35	1.50	1.645
3,000	13.10	1.10	1.25	1.40	1.55	1.70
4,000	12.61	1.131	1.287	1.443	1.60	1.755
5,000	12.15	1.17	1.33	1.495	1.652	1.81
6,000	11.75	1.20	1.37	1.537	1.705	1.87
7,000	11.27	1.24	1.42	1.59	1.76	1.935
8,000	10.85	1.282	1.465	1.645	1.825	2.00
9,000	10.45	1.32	1.51	1.70	1.90	2.07
10,000	10.10	1.365	1.56	1.755	1.968	2.143

EXAMPLE.—Take the case of three 2¼-inch drills at 60 pounds, at sea level. This requires a compressor with a free

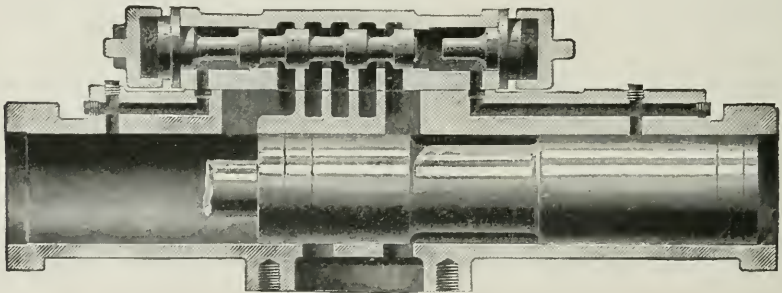


FIG. 244.—THE SLUGGER ROCK DRILL VALVE MOVEMENT.

air capacity of 133 cubic feet. Now if it is the desire to operate these drills at 80 pounds, and at sea level, the free air capacity of a compressor will have to be $133 \times 1.26 = 168$ cubic feet per minute. If the drills are to work at an altitude of 5,000 feet, and 70 pounds pressure at drill, the free air capacity required will have to be $133 \times 1.33 = 177$ cubic feet per minute.

IMPACT, OR THE FORCE OF PERCUSSION, IN HAMMERS AND PERCUSSION DRILLS.

The force of a blow from a hammer in the hand, of a drop press, a pile driver, a hammer, a rock drill; the falling of solid bodies, the water ram in pipes; and the power of projectiles, produce effects deducible from the general laws of dynamics applicable to such work.

The power of the hand hammer, which has not as yet been classed among the "mechanical powers," without doubt deserves the place of honor as the most ancient and, in many respects, the most wonderful mechanical power known. We daily see the results of its surprising force, effected without the complication of levers, wheels, or wedges; and apparently having some innate power superior to and independent of the principles of mechanics as commonly studied.

In order to enable any one to make the complete computation of the velocity of a drop hammer in the drop press, a cushioned air hammer, or the monkey of a pile driver, when the velocity is due to gravity only, the power of impact at the moment of giving the blow may be ascertained from the known height at which the velocity of fall commences. The effect due to cushioning of air and spring hammers will be an acceleration of velocity due to the gross pressure at starting, and will be described later on.

The square root of twice gravity ($\sqrt{64.33}$) multiplied by the square root of the height ($\sqrt{\text{height}}$) in feet; $\sqrt{2g \times h}$, or $8.02 \times \sqrt{h}$ = the velocity in feet per second at the instant of impact of a falling body.

Then one-half the square of the velocity $\times$ by the $\frac{\text{weight}}{\text{gravity}}$
 $\frac{v^2}{2} \times \frac{w}{g}$, or more simply the height of fall $\times$ by the weight, gives the number of foot-pounds due to the fall; and the distance at which the force of the blow is arrested is the measure of the

force of percussion or impact. It is as much more than the momentum in foot pounds as the distance of arrest bears to a foot. Thus, if at half a foot the impact is twice the foot pounds, at 1 inch it is 12 times, and so on through the fractions of an inch; at $\frac{1}{4}$ inch it is 48 times, and at $\frac{1}{32}$ inch it is 384 times. This latter arrest represents the impact of hardened surfaces, where the elasticity of the metals largely represents the small movement at impact, and of which the rebound of a hammer from the face of a hardened anvil represents the reactive effect of the foot pounds due to the momentum of the fall.

A small hammer swiftly wielded will accomplish that which would otherwise require a direct pressure of several tons. Seeking the cause of its mystic power, the principles of accumulated work or energy stored in weight and velocity will account for the varied effects we obtain.

In striking a blow with a hammer upon the head of a chisel there are two forces brought into action, viz., the force of gravity and muscular force to increase the velocity, so that, at the instant of striking, the hammer may have a velocity of from 20 to 50 feet per second; the effect at this moment is the same as if the final velocity had existed throughout the whole of the stroke. Assuming 32 feet per second as the actual velocity at moment of impact, then the force will be the same as if the hammer had fallen from a height of the square of the velocity, divided by twice gravity, $\left(\frac{v^2}{2g}\right)$ or $\frac{32^2}{64.33} = 16$ feet.

With a hammer weighing 2 pounds, then, the accumulated work or energy will be $16 \times 2 = 32$ foot pounds.

Supposing that the face of the hammer moves one-eighth of an inch after touching the head of the chisel before the energy is all absorbed, then the result will approximately be the same as a direct pressure or dead load of $32 \times \frac{12}{8} = 3,072$ pounds, or upward of $1\frac{1}{2}$ net tons; but this is only partially true.

More correctly it would be an average pressure of 3,072 pounds, being considerably more at the commencement of contact with the chisel and reduced at the end of the chisel cut to the mere weight of the hammer and chisel.

The hammer may be a self-adjusting mechanical power; for if the material be harder, so as to give more resistance to the chisel, the cut will not be so great, and therefore the force of percussion will be greater. For instance, if the movement of the chisel, as above stated, had been only one-sixteenth of an inch, the force would have been doubled or equal to a pressure of 3 tons instead of $1\frac{1}{2}$ tons.

But there is a limit to the effect; otherwise the blow would be measured by thousands of tons, until the rigidity of the mass receiving the blow was balanced by the elasticity of the material giving and receiving the blow. This is beautifully illustrated when striking the hardened face of an anvil with a hammer, where nearly the whole force of the blow is returned in the rebound of the hammer.

The intensity or quality of a hammer blow is of great importance in the various materials upon which it is used; the man of iron and steel using a quick blow, while the man of stone uses a slower blow with a heavier hammer, or the elastic mallet, which gives a pushing blow—each method being the best in its way, because suited to the material operated upon.

When we reach the domain of "power behind the throne," and have steam and compressed air to aid the force of a blow, the elastic force behind the hammer gives it the velocity due to impractical height of fall in large bodies, and thus adds power to a short stroke, and enables that control over the movements of a great steam or air hammer so necessary for the successful working of the immense forgings now being made. The later improvements in hydraulic forge hammers have enabled the enormous hammer pressure of 4,000 tons to be utilized in making the forgings for modern ordnance.

In computing the power of direct-acting steam or air-driven

forge hammers, we have the elements of the initial pressure, from which must be deduced the mean pressure throughout the stroke, the weight of the hammer, rod, and piston, and the length of stroke, from which to obtain the positive work of the hammer per stroke; against which are the back pressure from a cushioned blow, or the constant retarding pressure from the exhaust with a free stroke, together with the friction of the moving parts, which constitute the sum of the deductions to be made from the computed positive impact of the hammer.

For the purpose of arriving at the approximate power of percussion of a steam or air hammer, we may assume for the conditions of computation a weight of 4,000 pounds for the piston, rod, and hammer, with a diameter of cylinder of 20 inches and a maximum stroke of 3 feet, with air or boiler pressure at 100 pounds.

From the nature of the work of an air or steam hammer, both the pressure and stroke must be extremely variable below the limit of greatest capacity, so that for the maximum effect we have:

W = Weight of hammer, piston, and rod = 4,000 pounds.

S = Greatest stroke of piston = 3 feet.

P = Pressure, area of piston 314 square inches $\times$ 50 pounds assumed mean pressure = 15,700 pounds.

g = Gravity, or the velocity of a falling body at the end of one second of time = 32.16.

m = Mass = Weight divided by gravity = $\frac{4,000}{32.16} = 124.378$.

f = Total accelerating force $P + W = 19,700$ pounds.

a = Acceleration = $\frac{f}{m} = \frac{P+W}{m} = 158.388$.

v = Velocity of impact =

$$\sqrt{2 a S} = 2 S \frac{P+W}{m} = 30.827 \text{ feet per second.}$$

E = Energy =

$$\frac{m v^2}{2} = \frac{m 2 S \left(\frac{P+W}{m} \right)}{2} = S P + S W = 59,100 \text{ foot-pounds.}$$

If the energy of the blow is arrested by the compression of the forging and the spring of anvil in a distance of one inch from the point of contact, the measure of the force of percussion must be multiplied by the distance of arrest in fractions of a foot for its true value. Thus for one inch $12 \times 59,100 = 709,200$ pounds, or over 354 tons = the static pressure due to percussion.

In striking a cold mass of iron upon the anvil block with a yield of only one-quarter of an inch the enormous pressure of over 1,400 tons would be attained.

From the total accelerating force, the friction of piston, rod, and slides should be deducted; amounting in well-constructed, direct-acting hammers to from 3 to 5 per cent. The resistance to the power of a full hammer blow from the back pressure of the exhaust is of some importance, and may possibly amount to from 3 to 5 pounds per square inch, or about 10 per cent on the total effect, as above stated.

The effect of cushioning of the piston is a beautiful illustration of the control that can be made over an intense mechanical force, that by the mere movement of a hand may have its power varied from 0 to a percussion pressure of over 1,300 tons.

The action of a rock drill is somewhat unique in its persistence in overcoming the resistance of the various kinds of rock to its efforts to penetrate their depths. It does its work not so much by the high percussion pressure of a single blow, but rather by the quick repetition of blows just suited for effective work and for accomplishing a given depth of hole in the shortest possible time. Its peculiar valve gear and short stroke make its percussive force almost wholly due to pressure on the piston, which is made thoroughly controllable at the hand valve and feed screw. By this means the drill may be run at a stroke and pressure that gives the fastest cutting power; and as this may not be its longest stroke, which cushions the blow and reduces the number of blows per minute, a medium of from 75 to 85 per cent. of the full stroke is found to be most effective.

The friction of the drill steel in the hole, added to the friction of the piston rod, piston, and rotating device or rifle bar, is a serious drawback to the otherwise large theoretical power of percussive pressure in the rock drill.

Take, as an example, the theoretical percussive blow from a medium size rock drill of say 3 inches diameter of piston, running at 60 pounds pressure with 5-inch stroke, having an effective piston area, after deducting the area of the rifle bar, of 6 square inches; weight of piston and drill steel, 50 pounds.

The friction of the pipe and passages, throttling by the valve and back pressure from the exhaust, together with the following of the steam or air pressure for three-quarters of the stroke, will reduce the mean pressure to 40 pounds.

Then by the formulas as given for the steam or air hammer, the energy of the blow will be the total mean pressure on the piston multiplied by the stroke in fraction of a foot, plus the stroke multiplied by the weight, or 6 square inches $\times$ 40 pounds $\times \frac{5}{12} + \frac{5}{12} \times 50$ pounds = 120.83 foot-pounds.

Then if the drill penetrate the rock $\frac{1}{8}$ of an inch at each stroke the theoretical effect of percussion will be $\frac{12}{\frac{1}{8}}$ or $96 \times 120.83 = 11,699$ pounds, or nearly 6 tons static pressure.

A large allowance from the theoretical effect must be made for the actual effect, by the assumed value of the friction of the drill steel on the sides of the hole, and other moving parts, as well as for the resisting effect of water and débris of drilling, which always more or less clog the drill hole.

The average running time of drills on open rock work is about five hours per day, and the average of 250 strokes per minute or 75,000 strokes per day is probably a fair average day's work. This at $\frac{1}{8}$ -inch depth of cut and 10 strokes to make a circuit of revolution of the steel to complete the cut will represent $\frac{75,000}{96} = \frac{781}{10} = 78$ feet lineal depth of holes for a day's work in rock of medium hardness—limestone. In granite from

50 to 60 feet is about an average day's work, owing to the less penetration of the drill per stroke; while in marble, with dry short holes, a very much larger depth of holes, 200 to 250 feet, has been drilled. In this kind of work the actual running time of the drill is increased by the increased facilities of adjustment from hole to hole and the use of only a single drill steel.

The principles governing the force of a blow may be applied to the air hammer as used for chipping or riveting. The entire elimination of slides and drill friction in the air hammer leaves only the friction of the piston to be considered, and this is so small that 5 per cent of its percussive power is ample to be deducted from its total computed static pressure. A $1\frac{1}{2}$ -inch hammer piston, weighing 2 pounds, with 4-inch stroke, running with 60 pounds air pressure, will have 1.76 square inches $\times 60 \times \frac{1}{3}$ foot $= 35 + 2 \times \frac{1}{3} = 35.66$ foot-pounds per blow, less 5 per cent $= 33.8$ foot-pounds. If the chisel moves forward $\frac{1}{16}$ inch at each blow, then $33.8 \times 16 \times 12 = 6,489$ pounds is the static weight equivalent to each blow. Then if the hammer makes 500 blows per minute, $\frac{500}{16} = 31$ inches would be the length of chip cut per minute; and so on for any work of percussion by air hammers.

Chapter XXIII.

PNEUMATIC TOOLS. THE PNEUMATIC HAMMER AND ITS WORK

PNEUMATIC TOOLS.

THE PNEUMATIC HAMMER AND ITS WORK.

THE engineering industry at the present time is enjoying a period of activity quite unprecedented in its history, and, as a consequence, is calling for an immense increase in the number of its labor-reducing machines. Prominent among these are portable pneumatic tools and appliances, and it is not too much to say that there is every indication of their extended application. They have been used for a considerable time, although, with certain exceptions, they have not been well appreciated until the last few years, and considering their importance and the valuable assistance they are rendering to the shipbuilding and many other industries, it is somewhat singular that comparatively little information has been circulated about them except by trade descriptions. Doubtless some explanation for this is to be found in the fact that their practical application is of comparatively recent date, and further, that some of the earlier tools were unsatisfactory. Whatever the cause may be, it appeared that the subject was one which would be of vital interest in its relief to the weary muscle of the mechanic. The author, at the same time, is aware that the subject is by no means a new one to some of the leading and more enterprising firms, who have experimented with pneumatic tools for some years past; and he also recognizes that certain kinds of portable pneumatic riveters and other appliances have been in constant use for a considerable time, but he ventures to hope that the various tools described and illustrated in this work may be of interest, as showing what has been achieved up to the present date. The various tools which can be driven

by compressed air are many, and are rapidly increasing in number.

Since the mechanism employed for utilizing compressed air to secure a percussive action is essentially the same in both hammers and riveters, it will be sufficient to describe the mechanism in the different kinds, and for this purpose the hammer will first serve.

Hammers may broadly be divided into two types, viz., the valveless hammer and the valve hammer. This is a convenient description, yet perhaps not strictly correct, because although the valveless hammer has no valve beyond the striking piston, this is itself a valve to effect the proper admission of air to alternate ends of the working cylinder; while in the valve hammer a reciprocating valve, working either at right angles to or parallel with the striking piston, acts in combination with it to regulate the inlet and exhaust of the compressed air.

Valveless hammers have essentially a short stroke, and, although economical in air consumption in relation to the number of blows given, they will not compare with valve hammers in giving powerful blows which are necessary in heavy chipping or riveting. Owing, however, to their simple construction, they have probably a longer life than the valve hammers, and for such purposes as beading flues, light calking and chipping, and especially carving in stone, etc., they compare very favorably with valve hammers. The speed of the valveless hammers is very high, being 1,000 to 2,000 strokes per minute.

Valve hammers will probably secure the market for general and heavy chipping, calking, and riveting. Their speed for ordinary work ranges from 1,500 to 2,000 blows per minute, although they can be driven much faster. Their stroke, however, is considerably longer than that of the valveless hammers and the blow struck correspondingly greater. There is more air lost in the ports, but other advantages, including better control for using the air expansively, overcome this small defect. It is well known that the nature of a blow—whether light or

heavy—on various materials, produces an effect apart from the actual work done as measured in foot-pounds. For example, 10,000 small blows representing a certain number of foot-pounds might fail to produce a desired result, which a smaller number of heavy blows, representing less energy in foot-pounds, would effect. Having now considered the claims and advantages of the different types of hammers, all of which it may be stated can be worked economically at from 60 pounds to 80 pounds per square inch, reference must be made to the illustrations in order to explain their construction and action under compressed air.

Fig. 245 shows in section a "Ross" hammer in which the striking piston becomes the valve to control the admission and

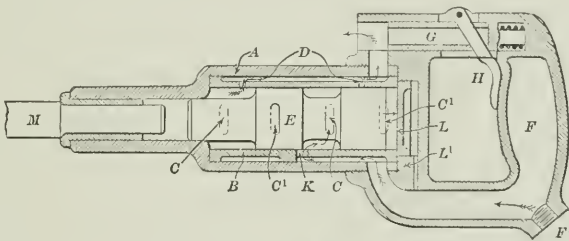


FIG. 245.—ROSS PNEUMATIC HAMMER.

exhaust of the working fluid. *A* represents the outer casing, made from solid drawn steel tube, bored and fitted with a phosphor-bronze liner, *B*, which forms the cylinder in which the piston works; *E* the striking piston made from a steel forging, ground to fit the cylinder; *D*, the exhaust ports, open to the atmosphere through the valve *G*, *C* and *C'* the admission ports, admitting compressed air to alternate ends of the piston; *K*, another port always open to the air supply; *G*, the exhaust valve; *H*, the trigger actuating the same; *F*, the phosphor-bronze handle, to which compressed air is admitted at the point *F'*; *L*, a piston cushion, has always full and constant pressure behind it from the air supply through the port *L'*; and *M* shows the working tool.

It must be noted that this hammer is caused to work by the

opening of the exhaust and not by regulation of the admission. The direction taken by the air under pressure when connected to the handle at H' will be readily seen by noting the arrows. The piston is slightly reduced in diameter in the middle, and the inside edges of the two collars thus produced form the cut-off edges for pressure, while their outsides govern the exhaust ports. It will be seen that when the piston is in the middle of its stroke there is a dead point, the compressed air finding admission only to the chamber formed by the reduced portion of the piston, since the ports C and C' are all cut off from admission of compressed air, but this does not interfere with its proper working, as the port cover is very small. Moreover, when starting, the piston will fall either to one end of the cylinder or the other by gravity, and when at work the momentum carries it over the dead point. The cut shows the front exhaust valve open, and the piston just commencing to make its forward stroke. Air flows through K , thence through the port C , passing between the annular space formed between the liner and the outer casing, and back through C' to back of piston, thus driving it forward. At the same time, exhaust takes place through D . The same action takes place on the backward stroke, when the forward ports, C and C' , are then in communication with K . In order, as far as possible, to eliminate vibration, a condition which is present in all hammers, the cushion piston, L , has been introduced at the rear of piston.

Fig. 246 shows in section a "Q and C" single hammer. A represents a bronze handle, in which is fitted the steel liner, B , which forms the working cylinder; C , the striking piston, which acts as its own valve; D , the outer cap, connecting the liner to the handle; E , the throttle valve; F , the trigger actuating the same; and G , the point to which the air supply is attached. The action of the hammer, on the trigger being depressed, is as follows:

The air having passed the valve, E , flows along the passage, d , and through a large air port into the cylinder or pressure

chamber; this has the effect of maintaining a constant pressure under the shoulder of the piston and tends to drive it backward. When, however, the ports *b*, in the piston *C*, which are also large openings, come into communication with the cylinder, the pressure fills the hollow portion of the piston and the cylinder in its rear, driving the piston forward to strike its blow. At this instant the piston ports come into communication with the exhaust port *c*, when the pressure

under the piston shoulder again returns the piston, and the blows are repeated in rapid succession—as many as 1,000 to 2,000 per minute. It will be noticed that in this arrangement of ports the air is used expansively. The same type of hammer is made in a modified form, being provided with a second piston placed in the rear of the other, the actuating fluid working between the two pistons for the forward stroke. It is claimed for this that vibration is reduced to a minimum.

Fig. 247 shows a hammer constructed on similar lines as the “Q and C” with the addition of a counterbalance piston,

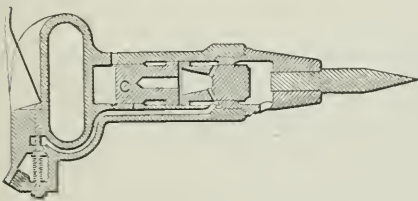


FIG. 247.—COUNTERBALANCED HAMMER.

ing cylinder, *C*, so that the tool, *T*, receives a blow alternately from the hammer piston, *A*, and from the cylinder, *C*, on the tool socket, *H*. The method of operation is shown by the differential piston areas. By the alternating motion and stroke of the two pistons the hand is relieved from jar.

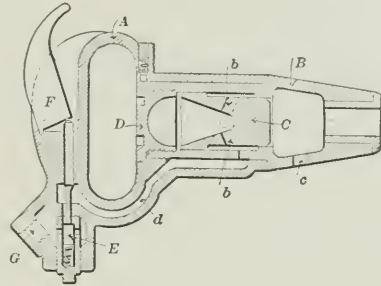


FIG. 246.—Q AND C HAMMER.

which by its reaction and cushion relieves the body of the hammer and the hand from excessive jar.

In the duplex riveter (Fig. 248) the striking piston, *A*, is encased in a strik-

Coming now to the valve hammers, to describe them briefly and the same time accurately is not an easy matter, because although they are simple in action and not excessively compli-

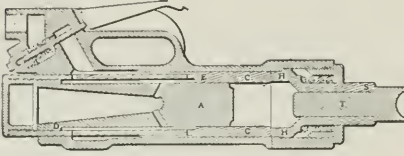


FIG. 248.—THE DUPLEX RIVETER.

cated with regard to the number of working parts, yet their movements and arrangements of ports are such as to make their description somewhat difficult.

THE "LITTLE GIANT" HAMMER.—This is illustrated in Figs. 249 and 250, to which the following reference applies: *A*, working cylinder; *B*, piston hammer; *D*, working tool; *E*, controlling valve; *E'*, steel seating for same; *F*, handle; *G* *G'*, throttle valve bushing; *H*, throttle valve; *I*, trigger actuating same; *a*, bore of cylinder; *a*², passage leading from cylinder to top of valve chamber; *a*³, passage from front end of cylinder to annular space in valve chamber; *a*⁴, exhaust passage at rear end of cylinder leading to exhaust through interior of valve; *a*⁵, bye-pass from *a*²; *a*, exhaust passage in forward end of cylinder to atmosphere; *b*, reduced portion of striking piston; *b*¹, annular chamber formed by such portion; *c*, opening into the controlling valve bushing; *c*¹, opening into cylinder from valve bush-

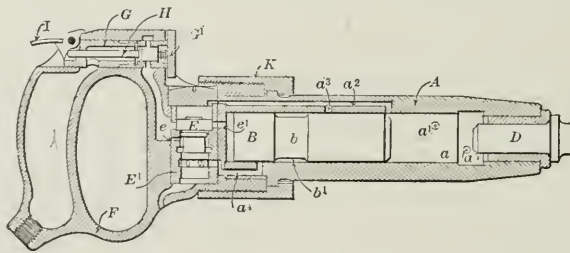


FIG. 249.—LITTLE GIANT HAMMER.

ing; *c*³, annular portion in valve bushing; *c*⁴, openings in valve *E*, leading to exhaust port, *c*⁵; *c*⁶, central chamber of valve; *c*⁶, exhaust to air in handle; *c*⁸, enlarged diameter of valve for cushioning; *c*⁹, recess behind *c*⁸; *c*¹⁰, small boss on top of valve. Fig. 249 represents a longitudinal sectional elevation of a ham-

mer with the striking piston at the rear end. Fig. 250 is a similar view, but of the opposite half, and showing the striking piston at the forward end of stroke. Figs. 251 and 252 show the handle and valve portion in section with the valve at the top and bottom positions respectively.

The action of the tool is as follows: air under pressure having been admitted by operating the valve *H*, passes through the opening *c*, and under the head of the valve *E*, thus forcing it in the position shown in Fig. 251. The air is then able to pass into the cylinder through the opening *c'*, and thus forces the piston forward into the position shown in Fig. 250. It will

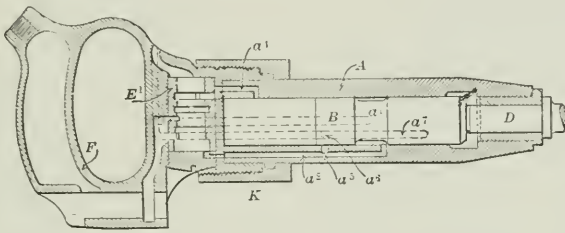


FIG. 250.—LITTLE GIANT.

Piston down.

be noted that the piston is reduced in diameter at *b*, which together with the cylinder forms a chamber, *b'*, so that as the piston nears its forward limit of stroke, air pressure enters the chamber *b'*, from the passage *a'*, which is in direct communication with space *c*. At the same time the passage *a²* is brought into communication with *b'*, and thus the air passes along to the top of the valve *E*, and forces it into the bottom position, as shown in Fig. 252. When the valve is in this position a clear way for the compressed air is open to the front end of piston through *c*, *c'*, and *a³*, thus effecting the return of the piston. Thus far the live air admission has been dealt with to drive both piston and valve in both directions. Coming now to the exhaust and taking the piston in its rearward motion first, the air escapes along the passage *a⁴*, and through the openings, *c¹*, in valve and out through *c⁵*. In its forward mo-

tion the piston exhausts first through a^7 , which leads direct to outer atmosphere. When a^7 is passed, the air escapes through a^3 , which is open to atmosphere through c^3 , c^4 , and c^6 , when the valve E is up. The exhaust of the valve is effected thus: During the backward movement of the piston, and as its annular portion is passing a^2 , it permits the air pressure on top of valve E to escape through a^2 , a^5 , into b^1 , a^6 , and a^7 , to atmosphere, with the result that superior pressure under valve head from c again lifts the valve. The valve is forced into its bottom position due to its area on the top being larger than the

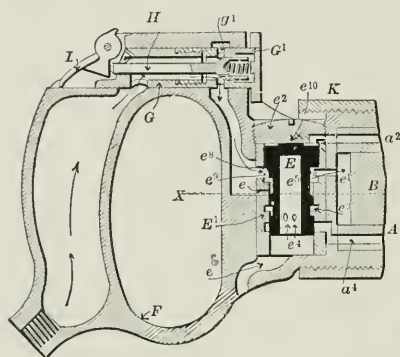


FIG. 251.—LITTLE GIANT.

Ready to strike.

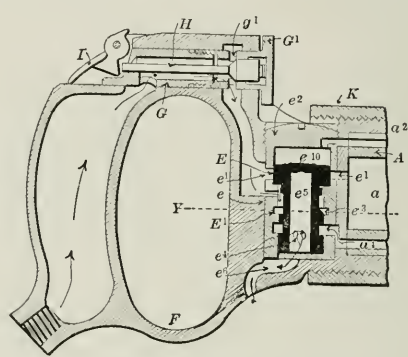


FIG. 252.—LITTLE GIANT.

Return stroke.

ring underneath its head. It is obvious that both the striking piston in its backward stroke and the valve in both directions should receive some form of cushioning, so as to reduce shock and prevent injury to valve and cylinder. In the piston this is effected by its closing the port a^4 , before the end of its stroke. In the valve the desired cushioning is secured in its upward stroke by means of the boss c^{10} , which causes the air to escape rather slowly into a^2 . In its downward stroke the cushioning is effected thus: The portion c^8 of the valve E is of diameter nearly equal to the small bore of the valve bushing, and there is also provided a small groove, c^9 , Fig. 251. When the valve is moving down, the portion c^8 first enters the small bore of the valve chamber, and this tends to retard the passage of the

air through the bore, and permits the excess of air to act as a cushion. Up to a certain limit the same hammer may be used to give light or heavy blows, and this may be effected by regulating the amount of opening given to the throttle valve. It is not desirable, however, simply to rely upon the trigger to do this, but preferably to provide a regulator, so that however hard the trigger may be pushed it only opens the valve the desired amount. In the "Little Giant" hammer this result is obtained by making the throttle valve bushing in two portions, G and G' . The part G is fixed to the handle, while G' is capable of being screwed in or out. The effect of this adjustment, when taken in combination with the valve H and the trigger I , is such that when G' is unscrewed, the port g' may be moved into such a position that the valve H can be pushed by the trigger I to the limit of its stroke without uncovering the port g' at all, and by adjustment of the part G' any desired opening may be given for the admission of air. In order to put the valve H in equilibrium a small opening admits the compressed air to either side of it, which, together with the spring shown, effects the desired result. It will be obvious that fewness of parts, and especially of joints, are desirable in the construction of a tool using compressed air at high pressure, since the possibility of leakage is thereby considerably reduced. Another feature of this hammer is the economical use of the compressed air, due to the cushioning of the moving parts taking place on the exhaust air rather than from the admission of live air, and taking this in connection with the solid construction of the valve, the same being well cushioned in both directions of its travel, the "Little Giant" type is likely to prove both an economical and a good wearing hammer.

THE "BOYER" HAMMER.—Figs. 253 and 254 show sectional views of a Boyer hammer, in which the following letters of reference indicate the various parts referred to: A , the working cylinder; D , the handle; G , the air passage from throttle valve to cylinder; G' , throttle valve; H , trigger actuating

same; *I*, the valve block; *I'*, cap at end of same; *K*, the working tool; *M*, the piston, consisting of a solid piece of turned steel fitting the bore of the cylinder and provided with a recess, *M'*; *O*, the valve; *P*, passage from cylinder to small space *e*; *Q*, passage from cylinder to small space *n*; *R*, passage from front end of cylinder to small space *m*; *S*, port leading from space *e* to front of cylinder through passage *R*; *T*, passage from cylinder through *U* to space *e*; *T'*, from air supply to cylinder; *X*, from air supply to *e*.

X is only necessary to supply air to front end of piston via *S* and *R* and to hold the valve in rear position. Other letters

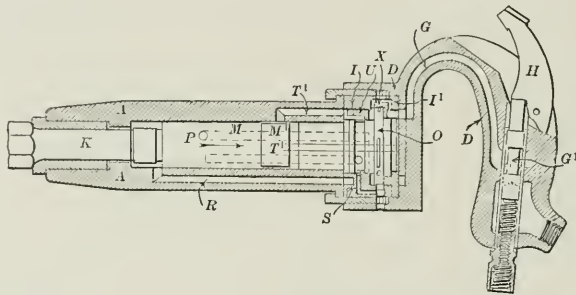


FIG. 253 THE BOYER.
ston down.

on the drawings are referred to in the following description of the working of the hammer:

Fig. 253 represents the piston in its forward and the disc valve in its rearward position. The compressed air having been admitted, passes along the passage *G*, and then into space *e'*, and acts on small area, *d*, of the disc valve *O*, and tends to force the valve forward, but air pressure in space *e*, admitted by the passage *X*, acting upon the large area of the valve, will hold the valve in the rearward position against the pressure acting on the small area. The air will pass from space *e*, through passages *S* and *R*, to the front end of the piston, driving the latter backward, the rear end of the cylinder being open to exhaust through the slots in valve *O* and groove *h*, the latter being constantly open to the atmosphere through passages

j, k. As the piston moves backward, it uncovers ports *P* and *Q*, and the pressure in front end of cylinder will exhaust through the groove and passages, *j, k*, to the atmosphere; the front end of the passage *P* will be uncovered by the front end of the piston at the same time as the front end of the passage *Q*, and the air in space *c* will escape through passages *P Q*, groove *n*, and passages *o, i, j, k*, to the outer air. Passage *P* being larger than passage *X*, by which the air is supplied to the space *c*, the pressure on the large area, *c*, of the valve *O* will be greatly diminished, so that the pressure acting on the small area, *d*, of the valve *O* will force the valve forward to the position of Fig. 253,

whereupon the ring of the valve *O* will close the passage *X*, and cut off the supply of air to space *c*, thereby permitting pressure to hold the valve in the forward

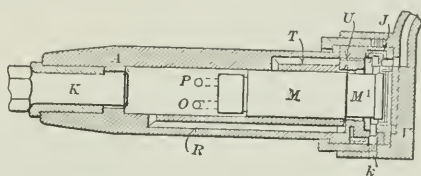


FIG. 254.—THE BOYER.

Piston up.

position. As the piston moves forward and finally strikes a blow on the chisel, the air in front can escape through passage *Q* until the latter is closed by the front end of the piston, and thereafter can escape through passage *R*, grooves *m, a*, and *n*, and passages *o, i, j*, and *k*, to the atmosphere. The recoil accomplishes most of the return of the piston. During the backward movement of the piston, the end of the cylinder is open to exhaust through slots *l*, in the valve *O*, and groove *h*, and passages *i, j, k*, until the passages *P* and *Q* are uncovered by the front end of the piston, at which time the valve opens, and, admitting air, arrests the piston and drives it forward. Although communication between *T* and *T'* is cut off almost directly the piston commences its backward movement, the valve *O* will not change its position—from rear to front—because sufficient air pressure is passing into space *c* through passage *X* to hold the valve, notwithstanding the escape of the air via *S*, since the latter is of less capacity than *X*. It will be readily

understood that the action of the compressed air along the passage *G*, acting first on one area and then on another area of the valve *O*, drives it in alternate directions, and that the valve in turn admits air to either end of the cylinder; at the same time the piston opens and closes certain ports in the cylinder, as in the case of the valveless hammer, and the combination of the dual motions of the valve and the piston produces the desired result of causing the piston to rapidly reciprocate and deliver a number of blows upon the tool. In this hammer it will be noted that the striking piston passes through the valve, which has the effect of increasing the stroke of the piston as compared with the original design of the hammer, in which the valve

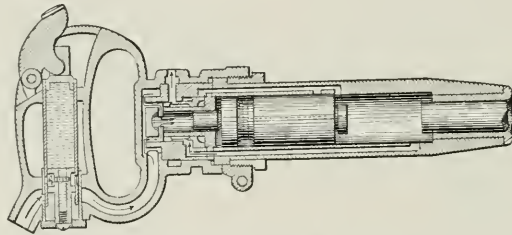


FIG. 255.—THE TILDEN PNEUMATIC HAMMER.

was arranged in a separate chamber immediately in the rear of the piston chamber, and without increasing the over-all length. In order to effect a cushion on the piston on the rearward stroke, live air is admitted before such stroke is completed. With regard to the valve, owing to its extreme lightness and shortness of stroke, cushioning of the valve is unnecessary.

The Tilden pneumatic hammer is illustrated in section by Fig. 255, which shows the general construction and also the oil chamber in the handle, which measures out and delivers a constant supply of lubrication to the incoming air. The reciprocating piston and valve are thereby constantly lubricated, a condition that of course increases the effectiveness and durability of the working parts. This tool is manufactured by the International Pneumatic Tool Company, of Chicago.

The sectional view herewith gives an idea of its construction

and operation. Starting with the parts in the position as illustrated, the motive fluid or compressed air from the main chamber passes through ports into the valve block chamber to press upon the upper end extension of the impact piston, and acting against the decreased area thereof imparts a light initial movement to the piston, which from practical experience is found to be very efficient in reducing the amount of jar or vibration.

Otherwise, the air ports and passages are similar in arrangement for operating the hammer piston as in other direct-acting hammers.

PNEUMATIC TOOLS OF THE CHICAGO PNEUMATIC TOOL COMPANY.

The "New Boyer" air hammers as now made are the outcome of several years of experiment to overcome the vibration of the older tools upon the hand and arm of the operator, when in use, as well as to simplify their construction and operation. Fig. 256 shows the four sizes of their short-stroke hammer as now made, with samples of chisels and calking tool.

The outcome of these trials is a modification of the hammer which greatly simplifies the construction. The proportions of certain operating parts have been altered so that the vibration is reduced to a minimum. The hammer is styled the "New Boyer" to distinguish it from the old form, which is still supplied to the trade if desired.

The general appearance and dimensions are not altered, the difference being in the operating valve. The valve mechanism of the new hammer is entirely different from the old, consisting of a single moving part; namely, the valve itself, which is formed of a thin cylindrical shell placed in the piston chamber, the piston travelling within the valve. By this arrangement a much longer piston chamber is obtained, hence a longer stroke, without increasing the length of the tool; also, the piston is cushioned at either end of the stroke. With a longer stroke the force of the blows of the piston is increased, and hence the

new hammer has about one-third more power than the old. The substitution of a simple piston valve for the complicated arrangement previously used insures a longer life for the hammer and fewer repairs. The regulating mechanism in the handle is not changed. For the best working of these hammers an air pressure of 80 pounds per square inch is recommended, but they can be operated with pressures varying from 20 to 100 pounds.

These hammers are made in four different sizes suitable for

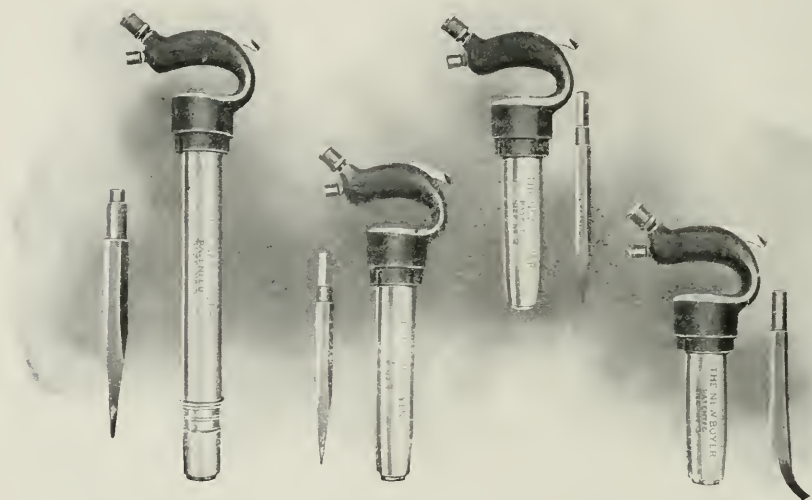


FIG. 256.—THE "NEW BOYER" AIR HAMMERS.

chipping, stone-carving, lettering, or tracing on marble or granite.

The No. 1 New Boyer hammer weighs 10 pounds, has 4-inch stroke at an estimated speed of 2,000 strokes per minute, and in operation requires about 20 cubic feet of free air per minute. This hammer is especially adapted to heavy work in chipping and calking, and also to light riveting, and has a capacity of driving up to $\frac{1}{2}$ -inch hot rivets.

The No. 2 New Boyer hammer weighs 9 pounds, has 3-inch stroke at an estimated speed of 2,500 strokes per minute, and

in operation requires about 20 cubic feet of free air per minute. This hammer is adapted to general use in chipping in iron and steel, and for calking on ship and boiler work. For chipping only, it is equipped with chisels having hexagonal shanks, and for calking, or for calking and chipping, where it is desired to use the hammer for both purposes, it is equipped with chisels having round shanks.

The No. 3 New Boyer hammer weighs 8 pounds, has $1\frac{3}{4}$ -inch stroke at an estimated speed of 3,000 strokes per minute, and in operation requires about 20 cubic feet of free air per minute. This hammer is especially adapted to beading locomotive flues

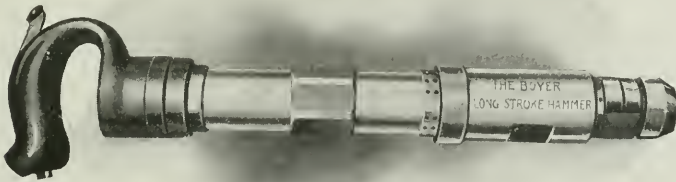


FIG. 257.—THE BOYER LONG-STROKE RIVETING HAMMER.

and to light calking. It operates best at an air pressure of 75 to 80 pounds. Will bead two flues per minute.

The No. 4 New Boyer hammer weighs 7 pounds, and is designed for very light work such as tank riveting.

Reputable concerns report that for chipping castings one man with a pneumatic hammer does the work formerly performed by three men. Fire-boxes are cut out with the aid of these tools in two and one-fourth hours, where the same work was previously done by contract, and eighteen and one-half hours allowed, while a total saving of ten and one-half hours on each fire-box is made by their use.

The Boyer long-stroke hammer (Fig. 257) is adapted to all kinds of rivet work up to 1-inch diameter of rivets. It weighs

18 pounds, and has a 9-inch stroke at an estimated speed of 800 strokes per minute. This is the most powerful pneumatic hammer made, and will meet the most difficult requirements.

The new No. 0 long-stroke hammer of this company weighs 13 pounds, and has a 5-inch stroke with an estimated speed of

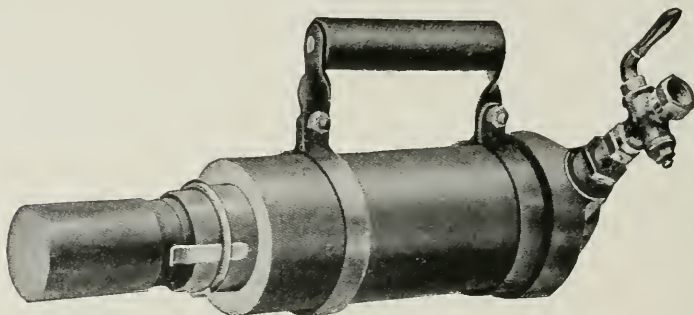


FIG. 258.—THE PNEUMATIC HOLD-ON.

1,800 blows per minute. Its most useful work is in chipping and driving rivets up to $\frac{5}{8}$ inch.

The hold-on (Fig. 258) has a piston and pressure air spring, and is also provided with an extension bar to hold it in position in confined places.

THE PNEUMATIC HAMMER AND ITS WORK IN STONE DRESSING.

Perhaps the most marked improvement in the stonecutter's art since the stone age has been the introduction of the use of compressed air. For centuries the hard, unyielding stone had been fashioned into shape by the ceaseless efforts of the hammer and chisel; and while other trades adopted newer and cheaper methods of manufacture in rapid succession, no means could be devised to hasten the tedious processes of stone-cutting.

The arm of the carver could deliver only a comparatively small number of blows per minute, but by the use of pneumatic carving tools this number was multiplied to such an extent that the blows following each other in rapid succession are in effect one continuous blow.

As the cutting power is always ready, the carver had merely to guide the machine and chisel. He can thus give his whole attention to his work, and the result is shown in the increased amount of work accomplished, and the work is done much better.

A machine for surfacing granite and other hard stone is in use in which a powerful pneumatic hammer is mounted on a radial arm, which is in turn supported on a vertical column or



FIG. 259.—THE PNEUMATIC HAMMER IN STONE DRESSING.

post, and is moved in a plane for the operation of the dressing tool in any required direction.

THE PNEUMATIC HAMMER AND ITS WORK IN SCULPTURE.

The beautiful work of the sculpture's art has now a hand-maid in the pneumatic tool, which is achieving wonders in the rapidity of its producing power. The relief to the weary arm is a helper to artistic thought, and the labor of the artist does not hang heavy on his mind. In this way, modern sculpture should not only advance in its output of volume, but should rise to a

higher degree of perfection by the relief from irksome muscular labor, and freedom of mind for the inception of beauty of thought and its transfer to the rigor of stone.



FIG. 260.—THE PNEUMATIC HAMMER IN SCULPTURE.

THE PNEUMATIC HAMMER IN THE PATTERN SHOP.

A PNEUMATIC FRET-SAW.—There has recently been made a new and interesting application of the pneumatic tool. This is a fret-saw directly attached to the piston of a pneumatic hammer and making from 1,000 to 1,800 strokes per minute. The saw is an ordinary keyhole-saw blade, and it may be made to follow the most difficult lines, of course cutting rapidly. Besides the evident use of the tool for the patternmaker and the cabinetmaker, it may be noted that it is employed in one of the largest packing-houses in Chicago for sawing ham bones, using a special saw with very fine teeth. This device has recently been brought out by the Chicago Pneumatic Tool Company.



FIG. 261.—PNEUMATIC FRET SAW.

THE PNEUMATIC HAMMER IN THE MACHINE SHOP.

Probably in no place else can the pneumatic hammer, and also the pneumatic drill, be applied to so many and so varied classes of work as in the machine shop. A line of air pipe



FIG. 262.—THE PNEUMATIC HAMMER IN THE MACHINE SHOP.

along the ceiling over the vice-benches, with the air hose attached to a hammer and a drill, standing upon the bench, ready for instant use, is the modern exemplification of economy in the production of machinery and manufactured goods, that has given the Western world an advanced position in the production and distribution of machinery used in the producing industry of all nations.

THE WORK OF PNEUMATIC TOOLS.



FIG. 263.—THE BOYER AIR DRILL IN SHIP WORK.
Held up on skids. On frame for bottom drilling.

The following illustrations show methods of using pneumatic tools in the various parts of the constructive work in ship-building; to these tools our steel ship-building interests owe much of their competitive success.



FIG. 264.—RIVETING.

The rivet boy and his work. The riveter and holder-on.

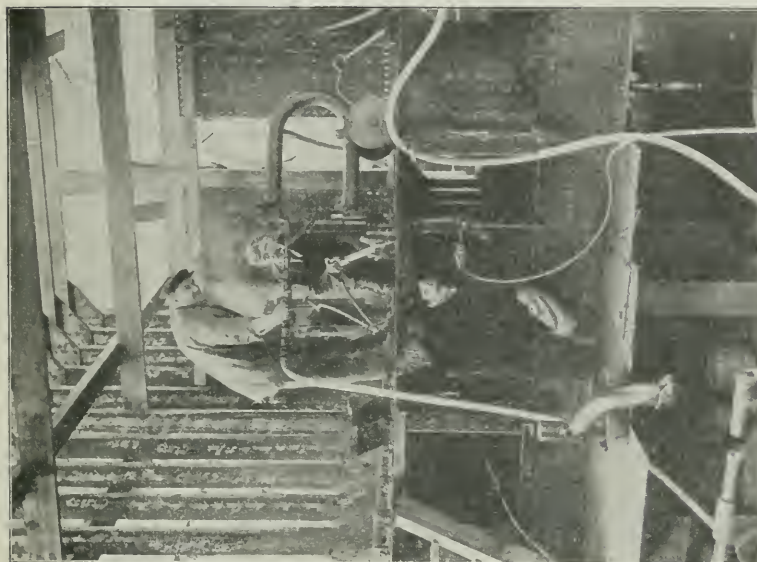


FIG. 265.—PNEUMATIC TOOLS IN SHIP WORK.

Riveting and clipping with pneumatic holder-on.



FIG. 266. THE RIVETER ON ADJUSTABLE BALANCE BAR.

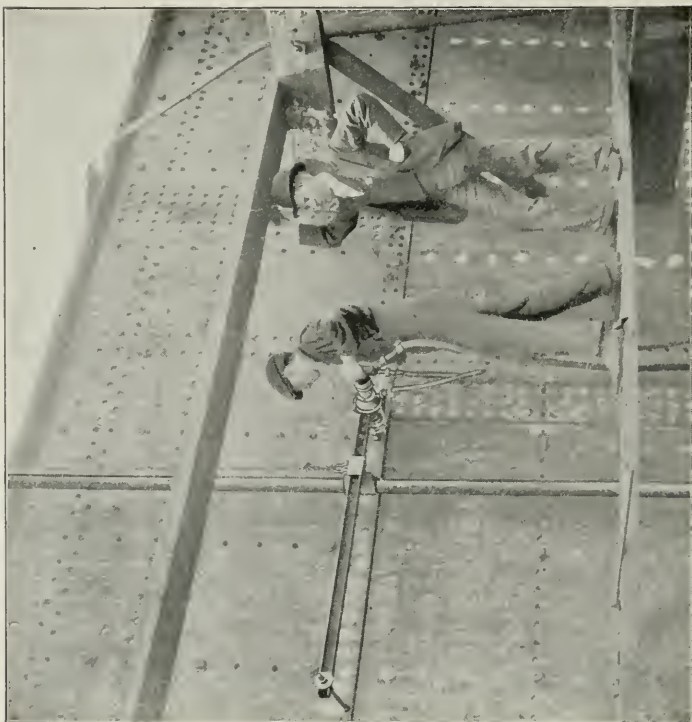


FIG. 267.—THE ADJUSTABLE BALANCE BAR IN SHIP-BUILDING.

The balance bar is counterweighted and slides upon a vertical rod; is quickly adjustable, relieving the workman entirely from the weight of the hammer.



FIG. 268.—RIVETING FRAMES AT THE WORKS.



FIG. 269.—THE LONG-STROKE BOYER IN SHIP WORK.

THE PNEUMATIC HAMMER AND DRILL IN SHIP-BUILDING.

The air hammer as a riveter on a balanced transverse beam with a ratchet stay or guide, is one of the late appliances for holding and steadying the hammer in deck riveting, and is illustrated in Fig. 270, while its method of operation is shown in Fig. 271.

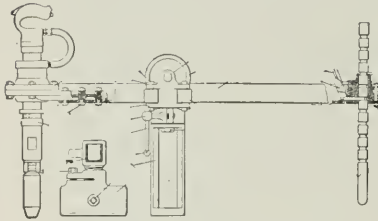


FIG. 270.—THE BALANCE BEAM.

It is one of the handy devices lately invented for the rapid work of deck riveting and for relieving the muscular effort of holding the hammer in constant and continuous work.



FIG. 271.—THE BALANCE BEAM IN DECK RIVETING.

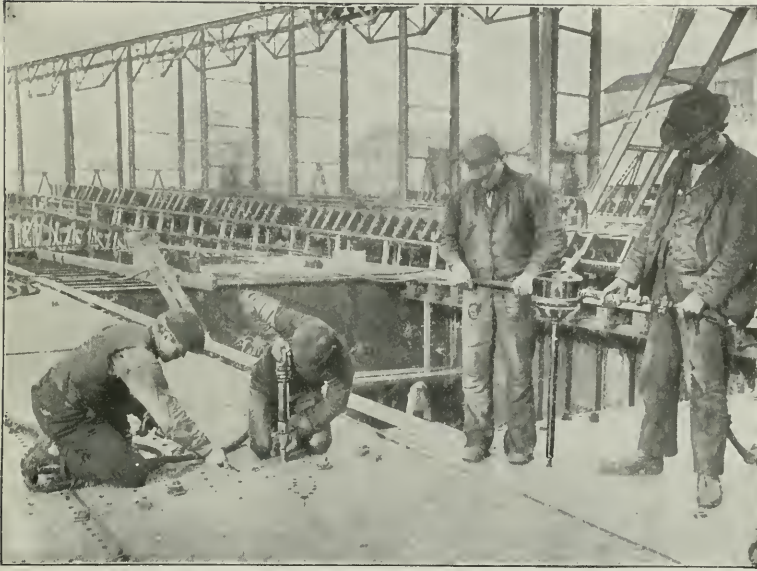


FIG. 272.—DRILLING AND RIVETING IN SHIP-BUILDING.

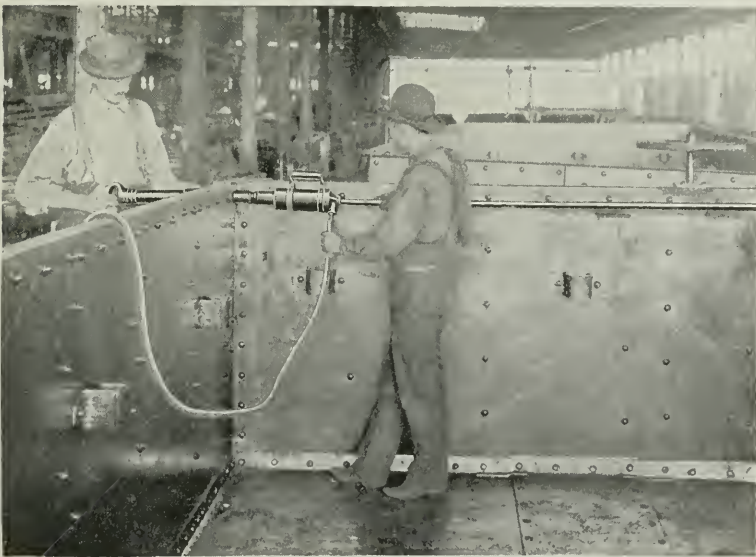


FIG. 273.—THE RIVET HAMMER AND HOLD-ON IN BULKHEAD WORK.



FIG. 274.—STRUCTURAL RIVETING.

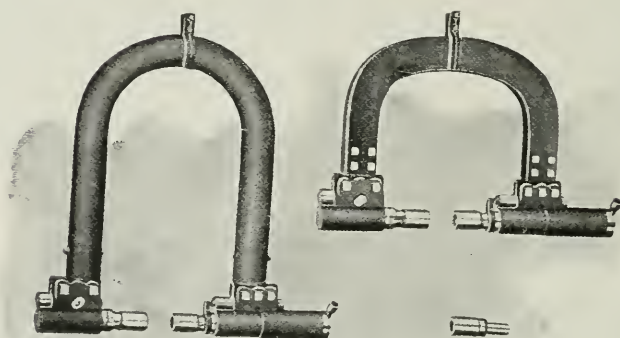


FIG. 275.—THE YOKE RIVETER.



FIG. 276.—THE LONG YOKE RIVETER.

THE BOYER RIVETER IN STRUCTURAL WORK.

No other improvement in the means of erection of modern structural work is so convenient and so economical as are compressed air tools. The air hammer and its mate, the air drill, have come to meet the needs of the times for quick work. This wonderful saving in time, which is a most important element in the erection of the great steel structures of modern days, has given an impulse to this class of structure that is felt throughout the civilized world, a marvel to all nations.

Probably no other class of construction tools has come in to use in a single decade, that has contributed so large a share to the relief of muscular labor in the new method of building with steel interframing, as the compressed-air tools. Their portability and the later methods of compressing air by portable compressors have gone hand in hand in this progressive age of building.

THE CHICAGO COMPRESSION RIVETER.

The compression riveters, Figs. 277 to 280, are unique tools for their special work. They embody in a compact form their own hold-on, and are operated by an air piston of large area pressing upon a hydraulic piston of small area, which pressure is transferred to the piston of the riveting plunger at right angles, thus generating the immense pressure required to compress a rivet at one stroke. These compact and powerful tools are hung and balanced on yoke slings and are easily managed in any position. The transfer medium between the right-angled pistons is oil with cupped leather packings on the pistons.

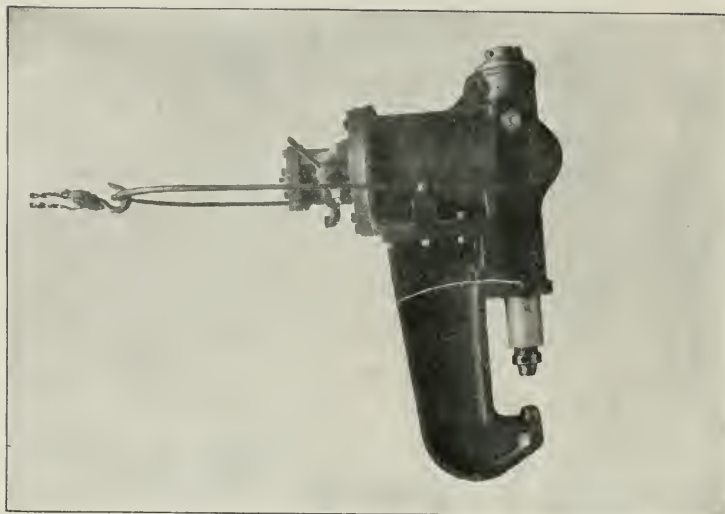


FIG. 278. SHORT-ARM PISTON RIVETER.
On sling.

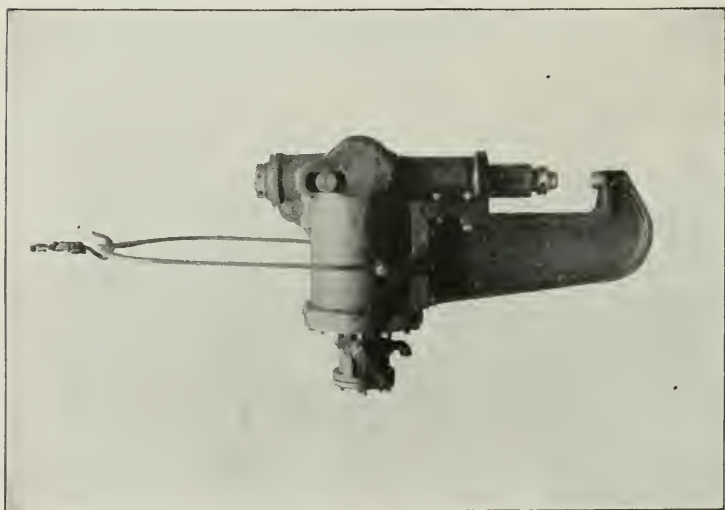


FIG. 277.—SHORT-ARM PISTON RIVETER.
With balance sling.

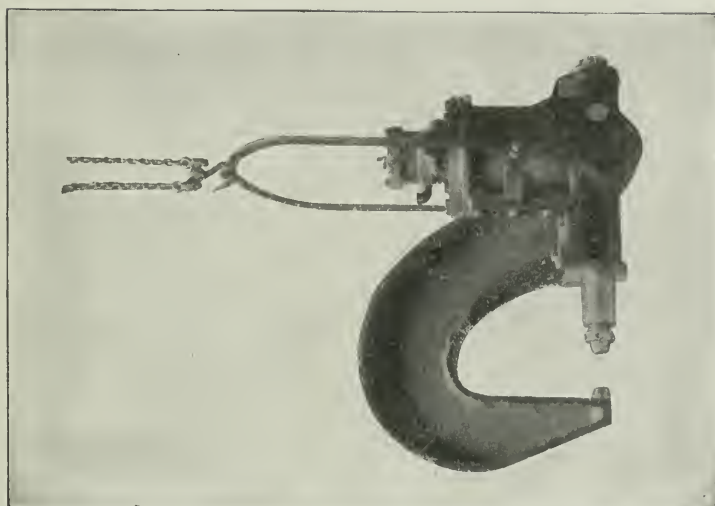


FIG. 28a. — PISTON YOKE RIVETER.
Horizontal position.

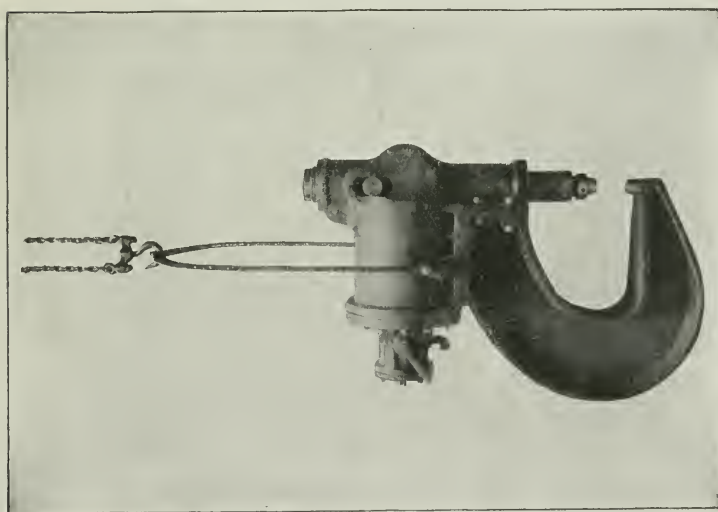


FIG. 279. PISTON YOKE RIVETER.
Vertical position.



FIG. 281.—CALKING A LARGE WATER PIPE.

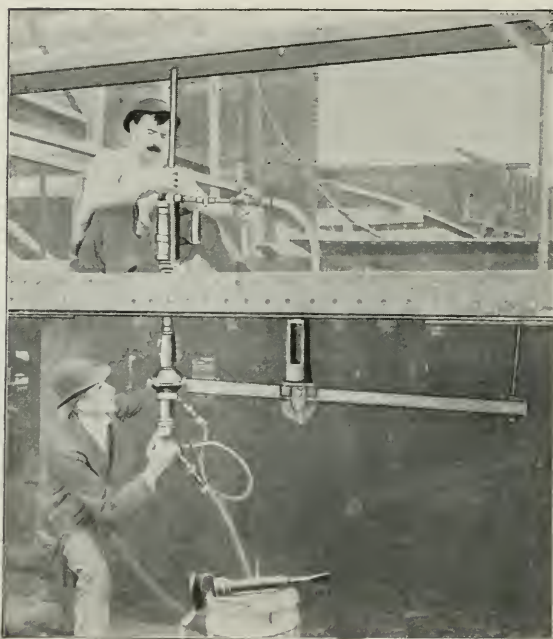


FIG. 282.—RIVETING WITH THE PALANCE ATTACHMENT.



FIG. 284.—RIVETER AND HOLD-ON IN SHIP CONSTRUCTION.

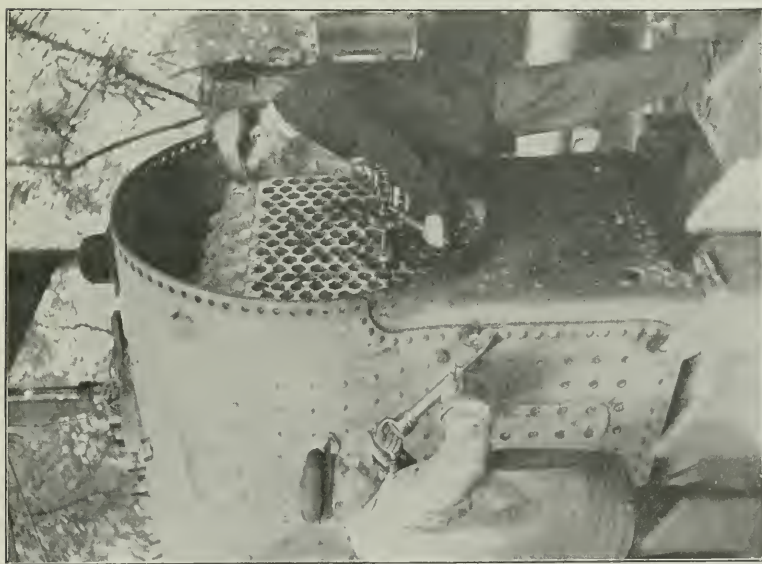


FIG. 283.—CALKING RIVETS AND RIMING TUBE SHEET, BOILER WORK.

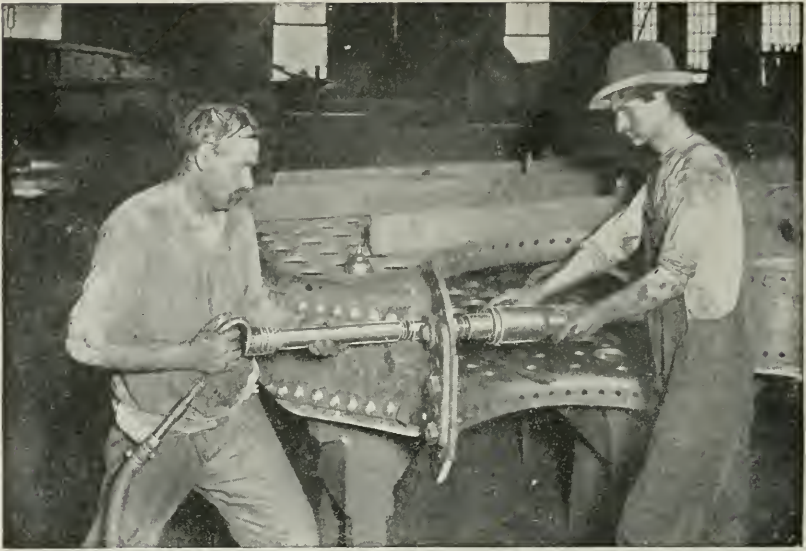


FIG. 285.—LONG-STROKE HAMMER AND HOLD-ON IN BOILER WORK.

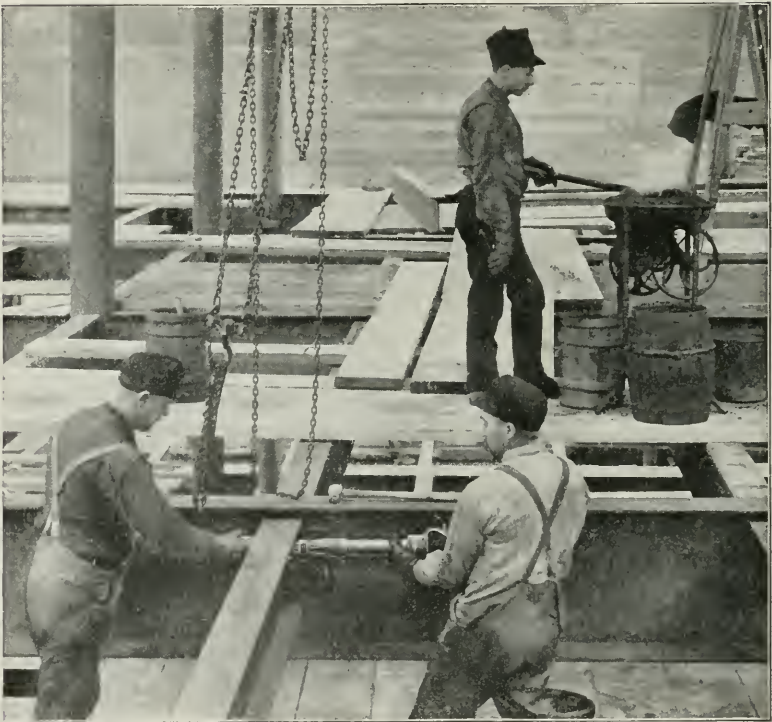


FIG. 286.—LONG-STROKE HAMMER AND HOLD-ON IN STRUCTURAL WORK.

COMPRESSED AIR DRILLS AND THEIR WORK.

The simple rotary air drill for hand use commends itself as one among the handy tools of a shop. It may consist of a rotary air motor fixed to the drill spindle, in a case to which the handles and breastplate are attached. Compressed air enters through the handle with the valve lever and is exhausted through the opposite handle.

Another form of rotary air motor drill stock, with simple blades held to the cylinder and central over the drill spindle, is illustrated on page 488.

The motor journals terminate in a small bevel pinion that meshes in a ring gear attached by the lower section of the case to the drill spindle, the handles being attached to the upper or motor section of the case.

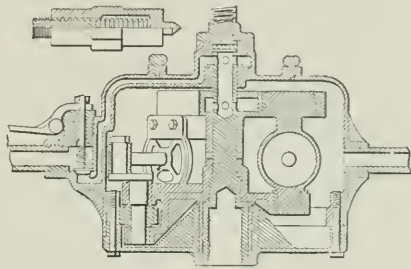


FIG. 287.—VERTICAL SECTION.

In Fig. 287 is shown the vertical section of an oscillating piston drill, in which one of the cylinders and trunnions is shown at the right, in the trunnions of which are placed the inlet and exhaust port. The air enters the revolving central spindle through the small holes shown in the hollow spindle and is delivered to the oscillating trunnion through the lower hole in the hollow part of the spindle.

In Fig. 288 are represented the outside view, the horizontal section, and the vertical section of a Haesler pneumatic drill. It is operated by four pistons in two cylinders, double-acting. The piston rods have a jointed connection to cam cranks on the pinion shafts. The piston valves are operated by levers pivoted to opposite piston rods, as shown in the horizontal section. The pistons act alternately in the cylinders so that there is no dead centre. The large spur wheel is attached to the spindle and revolves with it.

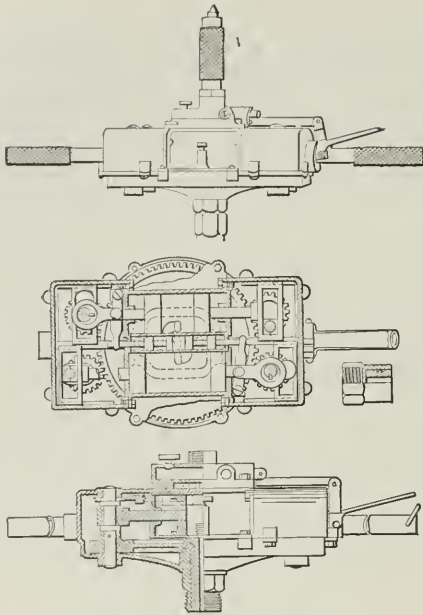


FIG. 288.—THE HAESLER DRILL.

In Fig. 289 are shown a vertical view and a sectional plan of a three-cylinder oscillating motor drill. The compressed air enters through one of the handles, its flow being controlled by a lever and valve. The exhaust enters the case from the port in the oscillating cylinder trunnions. The three double-acting pistons are directly connected to cranks and pinions which mesh with an internal spur gear, which is fast to the outer shell. The spider

which carries the cylinders and pinions is fast on the central spindle and revolves with it. The inlet and exhaust ports are shown in the horizontal section of the top trunnion at A.

In the succeeding illustrations are shown some of the standard types of pneumatic drills. Fig. 290 is a longitudinal sectional elevation of a "Little Giant" portable air drill, taken on the central line 1—1 of the horizontal section (Fig. 291).

In this type of drill the motor consists of four single-acting cylinders arranged in pairs, and having each pair of pistons connected to opposite ends of a double

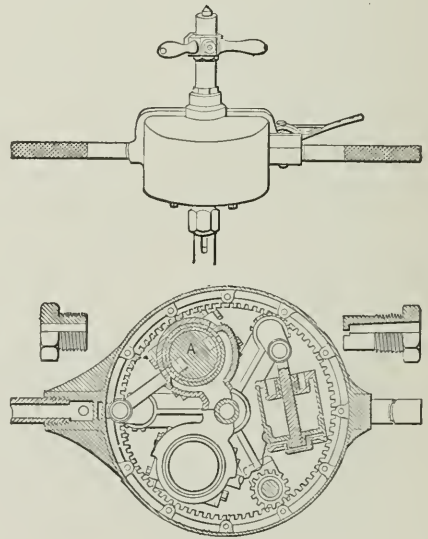


FIG. 289.—THE PISTON DRILL

crank-shaft. The pistons of each pair travel in opposite directions at all parts of the stroke to effect smooth running. The

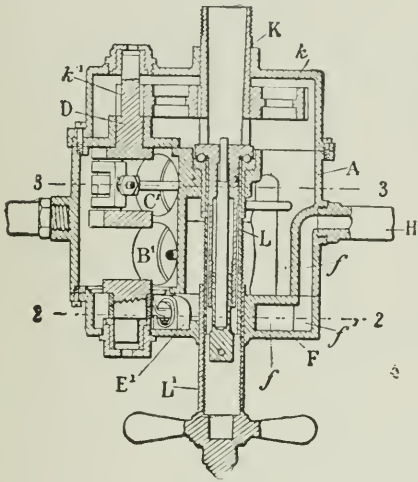


FIG. 290.—LITTLE GIANT, SECTIONAL ELEVATION.

range ment a dead centre is avoided. The air admission and exhaust are controlled by two piston valves, E and E' . These are worked by small eccentrics off the crank shaft, and serve to control the four cylinders; f is the main pressure chamber, having communication with the supply pipe H . The arrows show the direction taken by the air. Cylinders B and B' receive air communication through f^2 and f^3 , and cylinders B and B' through c^3 and c^4 , the exhaust taking place through the interior of the two valves.

The diagram shows a complex mechanical assembly in cross-section. At the top, there's a horizontal section representing a cylinder or valve mechanism with labels E and E' . Below this, a large circular component contains several smaller parts. A central vertical axis passes through the middle. To the left of the center, there's a label L near a curved surface. Above the center, there's a label C next to a rectangular block. Below the center, there's a label C' next to another rectangular block. On the right side, there are labels c^3 and c^4 pointing to specific features. At the bottom right, there's a label c^2 . In the upper right corner, there's a label C^1 . Various other unlabeled parts like bolts, nuts, and seals are visible throughout the assembly. Arrows indicate the flow of air or fluid between different chambers and pipes.

The action is as follows: f is full of live air which is blowing through c^1 and f^3 , to supply cylinders C and C^1 , while cylinders B and B^1 are exhausting through f^2 and c^3 into the centre of the valves, and thus to the atmosphere. Referring to

cylinders are controlled by balanced piston valves set to cut off at five-eighths of the stroke, and should therefore prove economical. Referring to Figs. 290 and 291, *A* is the main casing, which contains the mechanism; *B* and *B'* are one pair of cylinders, and *C* and *C'* are the other, arranged at right angles to each other and connected to a common crank shaft *D*. By this ar-

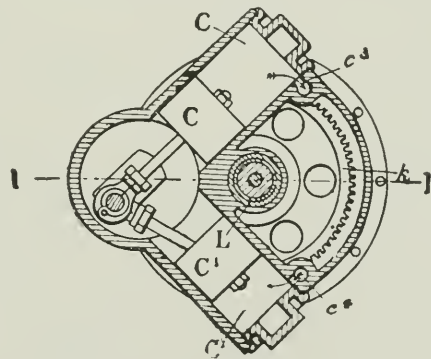


FIG. 291.—LITTLE GIANT, SECTION THROUGH CYLINDERS.

Fig. 290, k and k^1 are gear wheels by which the rotary motion of the crank-shaft is conveyed to the part K , which is fitted

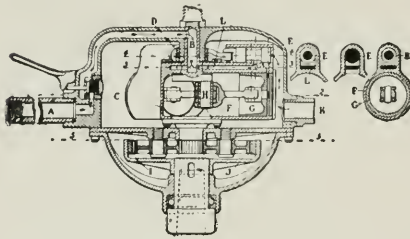


FIG. 292.—LITTLE GIANT, HIGH SPEED.

with a suitable drill-holder or chuck. L is a threaded sleeve, which, in conjunction with L^1 and other parts, provides for feeding the drill. This tool is also furnished with a simple reversing arrangement, which enables it

to do all classes of work for which a drill is suitable; for this it is fitted with a handle in the place of the star centre. By revolving this handle a valve placed in the main pressure chamber reverses the direction taken by the air when entering the valve bushing, suitable ports being provided.

Figs. 292 and 293 illustrate the "Little Giant" high-speed rotary drill, which consists of a casing C containing three rotating cylinders F , each of which is governed by a piston slide valve E . These valves rotate with and work in cylinders or valve chambers forming part of the main engine cylinders F . In other machines for effecting the same and similar purposes

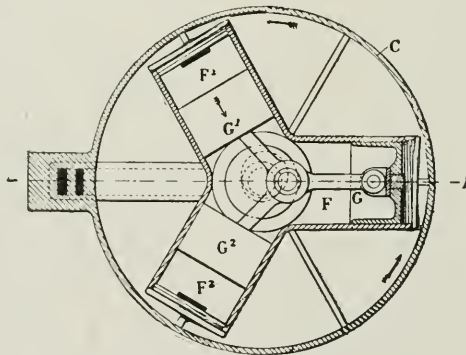


FIG. 293.—LITTLE GIANT FIXED CYLINDERS.

the casing is used as a live-air chamber; in the "Little Giant" type it is used as an exhaust receiver. Again, in other machines the air is directly admitted into the casing C or

live-air chamber, whereas with the "Little Giant" drill it is carried through a separate channel from the supply pipe *A*, and through a stationary or fixed hollow crank-shaft *B*, into a passage *L*, leading to the reduced portions of the piston slide valves *E*, and according to the position of such valves admitted to, or exhausted from, the cylinders *F*. It will also be noticed that in the "Little Giant" drill the exhaust does not blow through the gear mechanism, since it is so arranged that it is admitted into the main casing *C*, which is itself sealed from the lower portion of the machine, containing the reducing gear, so that the exhaust passes out through a separate pipe *K*.

The leading feature in the "Little Giant" machine is that it combines a high-speed engine with a low consumption of air, and this result has been obtained by employing a stationary eccentric, which is set at the required point in the throw of the crank to obtain the necessary cut-off, the cylinders *F*, and their governing slide valves *E*, rotating about this eccentric. As is well known, in engines of this type the travel of the eccentric should be quickest when the motion of the piston is slowest, and this is provided for in the design by having a very quick port opening and an equally quick release, thus enabling the rotating cylinders to move at an exceedingly rapid rate, the air not having to travel through tortuous passages either in or out.

Fig. 294 illustrates a transverse vertical section of a

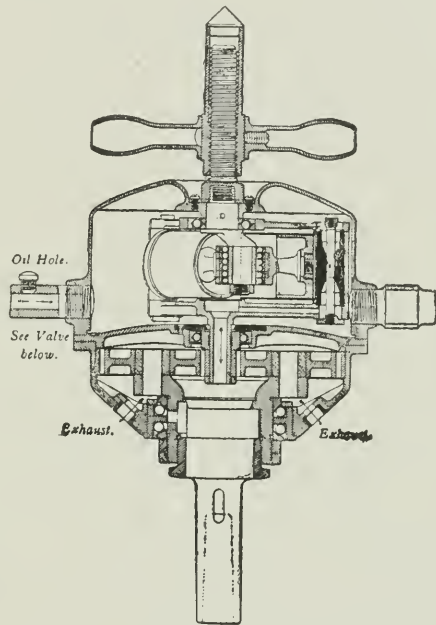


FIG. 294.—SECTION, BOYER DRILL.

"Boyer" piston drill, and Fig. 295 is a horizontal section taken through the centre of the cylinders. The machine consists of three main parts: (1) The upper housing into which the throttle valve and steadying handle are screwed, and which forms a live-air chamber carrying the motor; (2) the diaphragm which forms the lid or cover of the upper housing or live-air chamber, and through which the hollow exhaust spindle projects; (3) the lower housing secured to the upper housing by means of screws, and containing the gear-wheel rack bearings for drill spindle, etc. The motor is in the form of a three-cylinder single-acting oscillating engine, the cylinders being

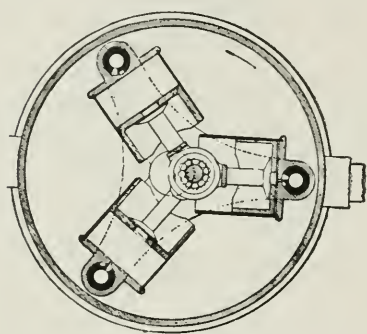


FIG. 295.—HORIZONTAL SECTION, BOYER.

carried in the rotary frame.

This frame consists of an upper and a lower plate, and is triangular in shape and free to revolve round its centre on two bearings, the lower one being a hollow shaft, connected by gearing to an internally toothed wheel in the lower half of the casing. The admission of air

to the cylinders is regulated by the valves formed in the pivots upon which the cylinders oscillate. The cylinders are single acting, and the inner ends are open; therefore air under pressure, of which the upper casing is always full, has free access to the pistons on that side. It would seem, therefore, that air being admitted through the pivot valves would only produce equilibrium; but since one of the cylinders is always open to the exhaust through the hollow bearing of the triangular frame, this equilibrium becomes disturbed, and the compressed air has full effect upon each piston as the valve comes in line with the exhaust. The cylinders are constructed of steel tubes, and are fitted with trunk pistons having their connecting-rod ends attached to a fixed crank-pin common to them all. The pistons are set in motion by the introduction of

compressed air into the upper casing and into the cylinder as already described; this has the effect of causing the three cylinders, together with their triangular framing, to rotate round the fixed crank pin, and thus transmits rotary motion to the spindle by means of the gearing before referred to. This class

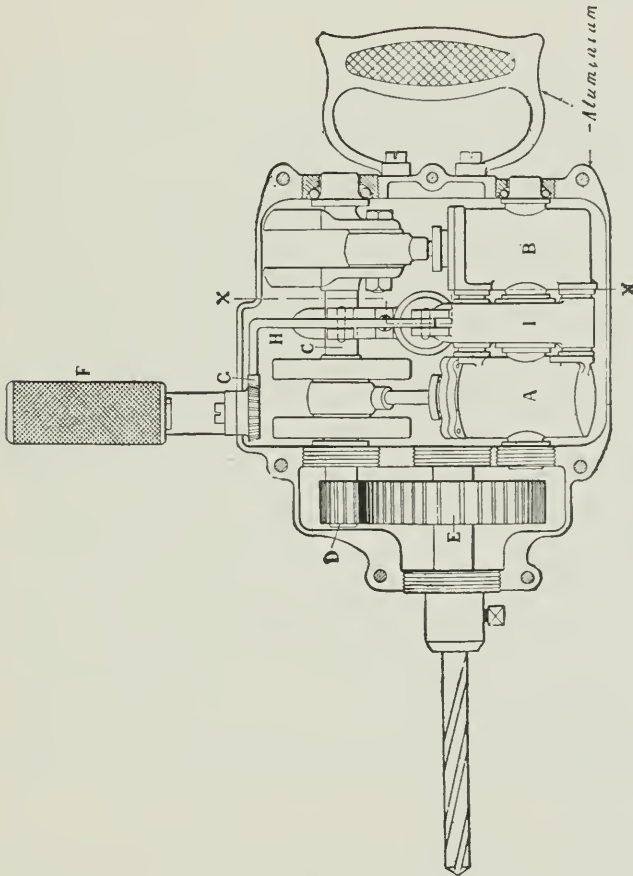


FIG. 296.—THE WHITELOW DRILL.

of machine is fitted with a regulator by means of which the power and speed of the drill can be varied as desired.

Fig. 296 shows the interior of a "Whitelaw" reversible drill with half the casing removed, showing the piston valve *I* and the passage of the air leading to the cylinder and the method of reversal. This type of drill is actuated by two double-acting

oscillating cylinders *A* and *B*, driving a crank shaft *C*, to which is attached a pinion *D* driving the gear wheel *E*, attached to the drill spindle. Its action is therefore at once apparent; for by rotating the milled handle *F*, which gears into the short rack *G* at the end of the lever *H*, the hollow portion of the piston valve *I* changes its position, with the result that reversal takes place in the usual way adopted in oscillating cylinders. The exhaust is made into the casing and escapes through suitable apertures. The reversal is instantaneous, and the machine is well adapted for all kinds of drilling, tapping, tube-

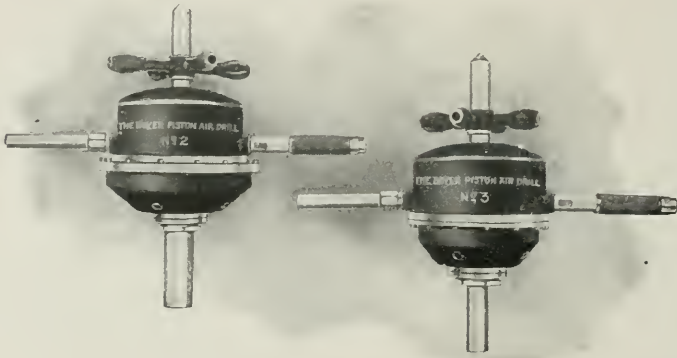


FIG. 297.—THE BOYER PISTON AIR DRILL.

expanding, wood-boring, etc., the reversing arrangement especially lending itself to such purposes. The machine is supplied with ample lubrication, and is fitted with ball bearings throughout.

The Boyer piston air drill is of the three-piston type, and is adapted for drilling iron and steel up to three inches in diameter (Fig. 297). It is used extensively in boiler shops, shipbuilding concerns, machine shops, architectural works, foundries, etc. Many appliances are used in connection with these drills, such as flue rollers, grinding-chucks, flue cutters, stay-bolt cutters, and side-light cutters.

Fig. 298 shows the method of driving countersunk flush rivets on the bottom of a vessel by compressed air. The small

hammer seen in the illustration is used for chipping the head of the rivet smooth, and the drill is used to ream the rivet holes to a sufficient diameter to receive the rivet.

The pneumatic rotary motor drill stock consists of a horizontal rotary motor, over the centre of the spindle, having on one end of its shaft a bevel pinion, which drives a bevel gear

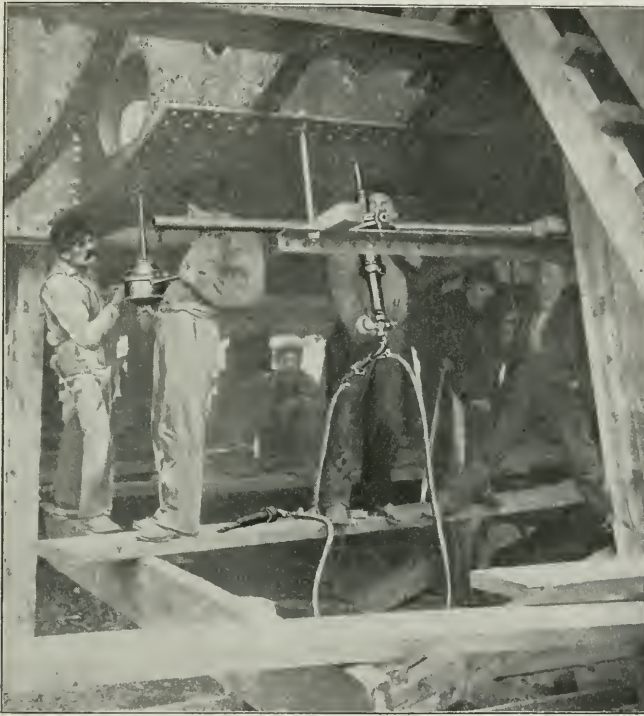


FIG. 298.—THE PNEUMATIC DRILL AND HAMMER IN SHIP WORK.

attached by the lower section of the case to the drill spindle. The inlet and exhaust ports and valves are shown in the vertical section.

The rotary drill, as shown in Figs. 300-302, is the early type of pneumatic drill, and is still extensively used on heavy drilling and reaming. Its simplicity of construction and small number of working parts give it some advantages over the more complicated types of air drills.

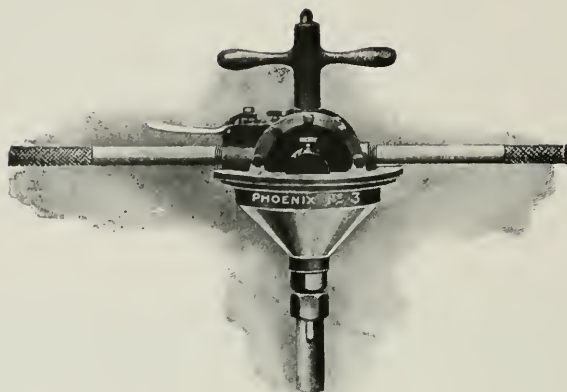


FIG. 299.—THE PHOENIX ROTARY AIR DRILL.

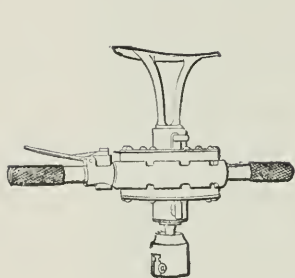


FIG. 300.—ROTARY BREAST DRILL.

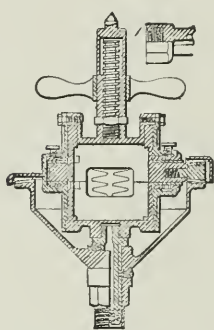


FIG. 301.—THE ROTARY.

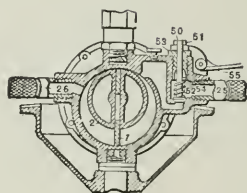


FIG. 302.—SECTION.

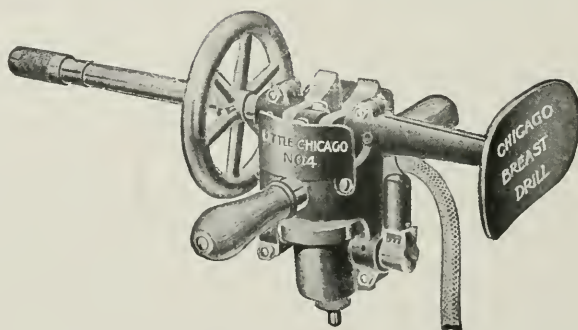


FIG. 303.—THE LIGHT BREAST DRILL.

The Chicago breast drill is of the oscillating cylinder type, and is capable of drilling up to $\frac{1}{2}$ inch in iron or steel. It is an invaluable tool where a large number of small holes are to be bored. It is used for wood-boring with equal success.

Fig. 303 is an illustration of the Chicago rotary breast drill, a very light, compact drill capable of drilling up to $\frac{3}{8}$ inch in metal.

Fig. 304 is a larger-sized drill of the same type as in the preceding illustration, and is adapted for drilling up to $\frac{7}{16}$ inch in

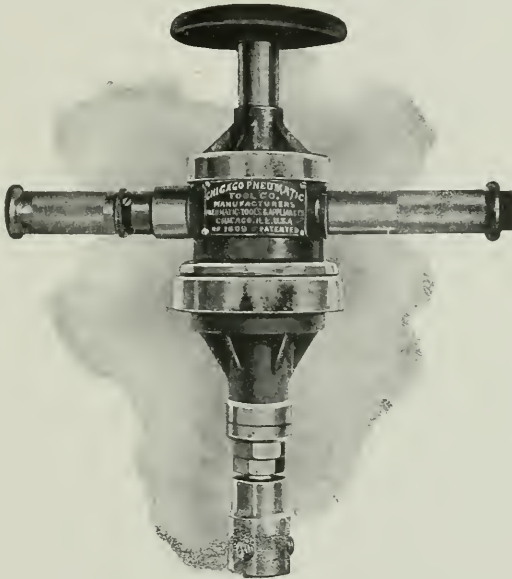


FIG. 304.—THE MEDIUM BREAST DRILL.

Weight, five pounds.

metal, and also for light wood-boring. It can be used with feed screw. It is employed in shops having a lighter grade of work both in iron and brass; also in wood-working establishments, in the building of small wooden vessels, where a great number of small holes are to be bored.

The Whitelaw types of reversible drills are for all kinds of wood-boring. They are used extensively in car shops, wood shipyards, etc.; are very light, and will bore up to four inches diameter in about one-fifth the time required by hand methods.

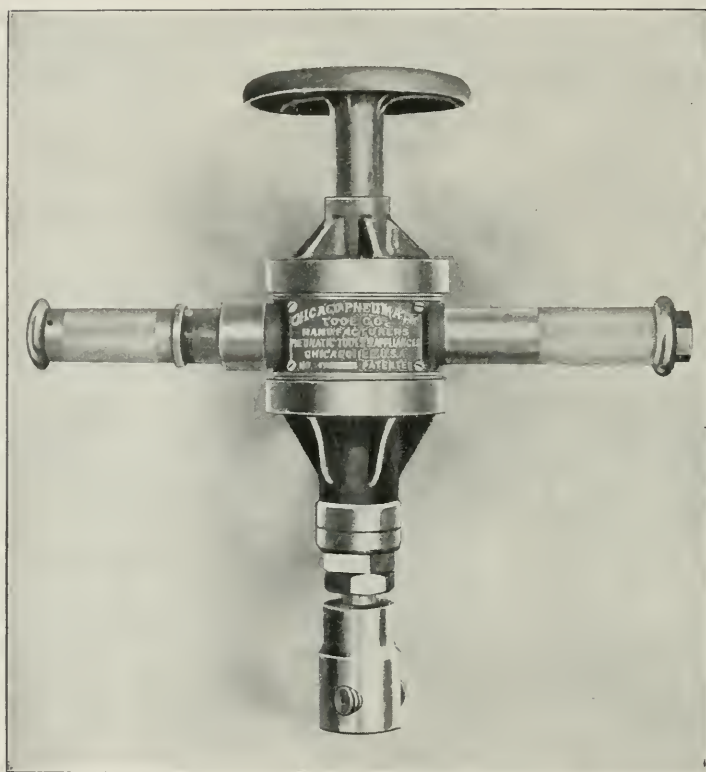


FIG. 305.—THE CHICAGO BREAST DRILL.

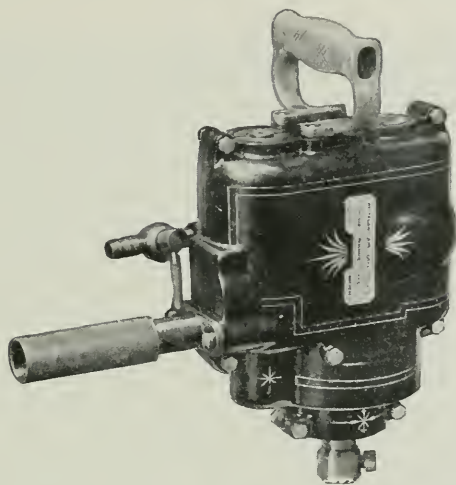


FIG. 306.—WHITELAW REVERSIBLE DRILL.

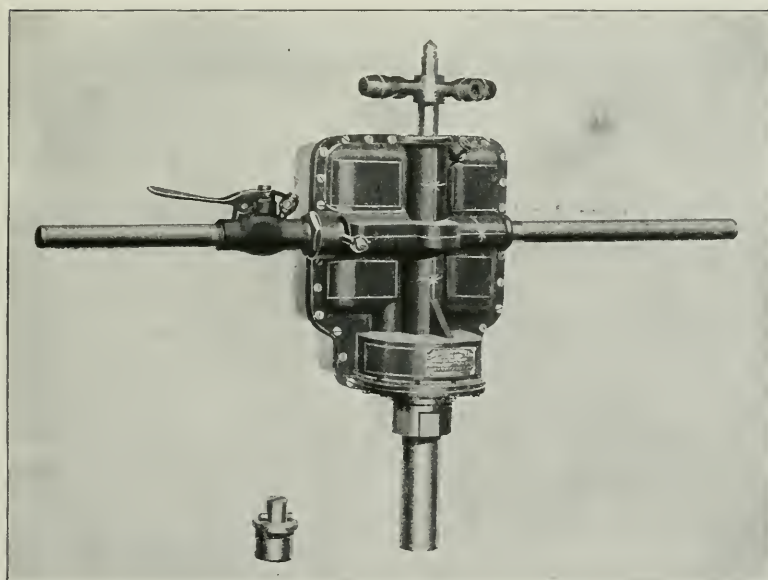


FIG. 307.—WHITELAW REVERSIBLE WOOD-BORING DRILL.
Weighs ten pounds, and will bore up to four inches diameter.

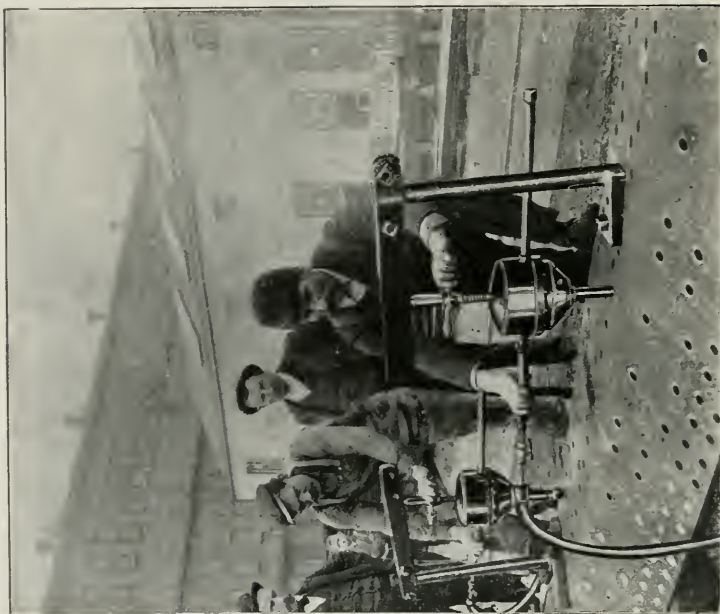


FIG. 309.—DRILLING PLATES.
With air drills and clamps.

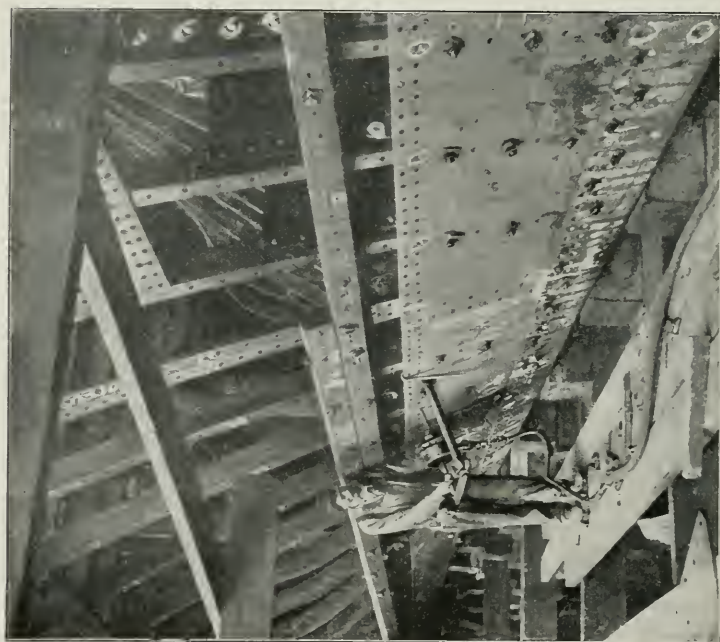


FIG. 308.—THE AIR DRILL IN SHIP-BUILDING.
Drilling plates with a clamp.

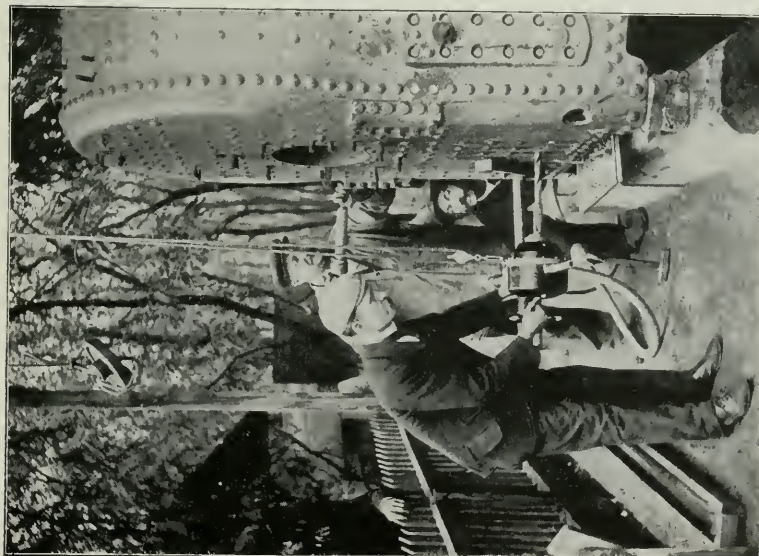


FIG. 310.—DRILLING AND RIVETING.
The pneumatic tools in boiler work.



FIG. 311.—THE BOYER DRILL WITH ANGLE GEAR.
For boring close to a wall.

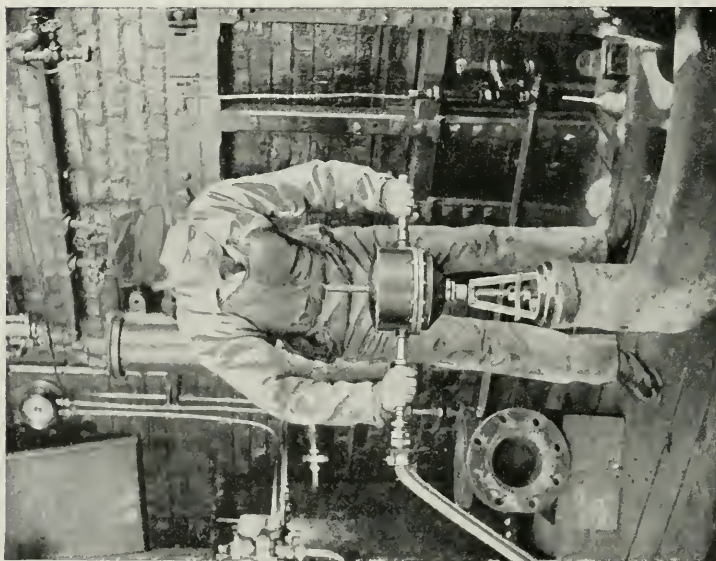


FIG. 312.—THE BOYER PISTON MOTOR.
With ring chuck, grinding steam joints.

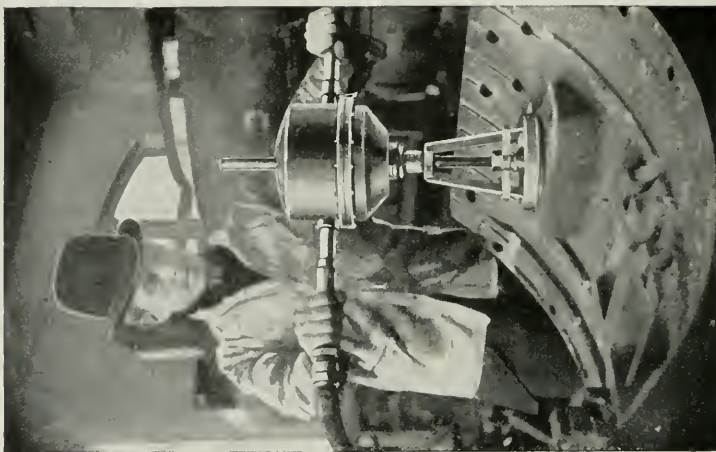


FIG. 313.—THE BOYER PISTON MOTOR.
With ring chuck, grinding steam joints.

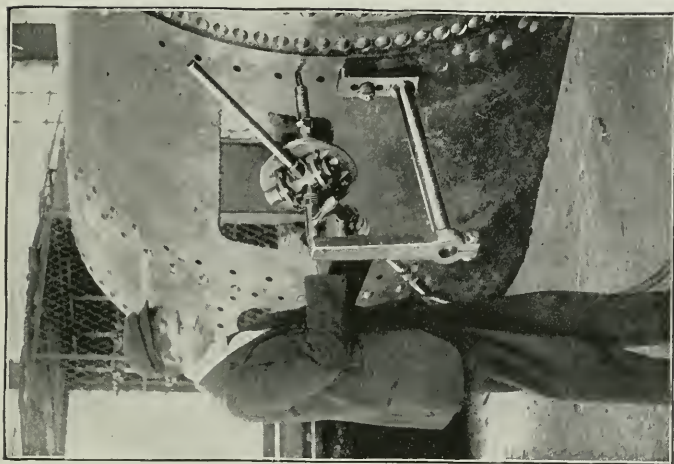


FIG. 315.—THE PHENIX ROTARY DRILL.
On boiler work, reaming, or drilling.



FIG. 314.—THE BOYER PISTON DRILL.
Boring wood.

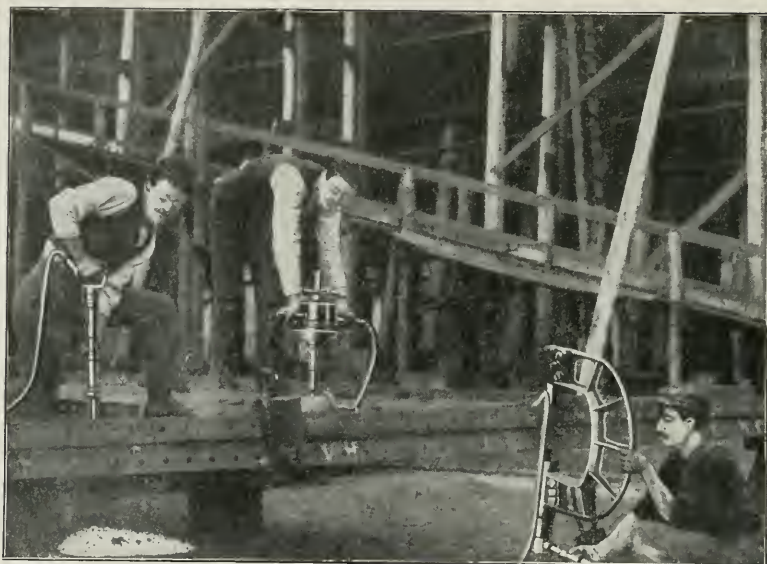


FIG. 316.—DRILLING AND RIVETING WITH PNEUMATIC TOOLS.



FIG. 317.—DRILLING MANHOLE IN A TANK.

Chapter XXIV.

PNEUMATIC TOOLS—Continued

PNEUMATIC TOOLS.

(Continued.)

PNEUMATIC HAMMERS OF THE Q. & C. COMPANY, NEW YORK CITY.

THE hammers of this company are made in four sizes, and are used with pressures of from 80 to 90 pounds for their best work. Fig. 318 shows this hammer in section, consisting of a differential cylinder case containing the air passages for press-

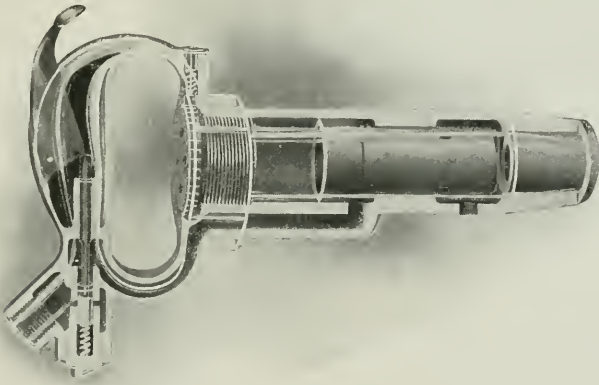


FIG. 318.—SECTION OF THE Q. & C. HAMMER.

ure and return stroke, and the relief chamber and exhaust port. In the handle the spring-closed air valve and thumb lever are plainly shown. The piston has a differential action in which the annular chamber due to its enlarged upper section allows the up-stroke to be made with a small piston area subject to pressure, and a much greater area on the down-stroke for its greater work. The piston has a hollow centre leading to a side port, which exhausts the down-air pressure at the moment of closing the inlet port and simultaneous with its impact with

the tool or chisel. The piston is returned by the pressure in the annular section.

In Fig. 319 is shown a lettered section of the Q. & C. pneumatic hammer, the basis of construction of which is the Johnson patent. The small globular chamber *A*, together with the conical chamber in the piston, is charged with compressed air at the moment the air port *S* reaches the inlet space *Po*, when the elasticity of the air in the chamber carries the piston forward, closing the inlet port and pushing the piston to its stroke, when the air is exhausted at the chamber and port *E*. *F* is the flexible hose connection, and *T* the air-valve trip. The

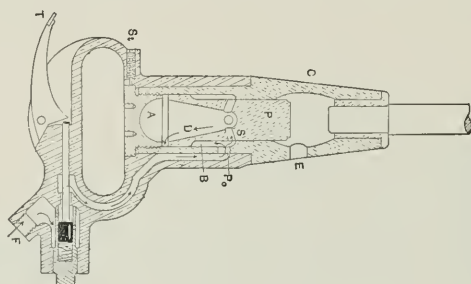


FIG. 319.—SECTION OF Q. & C. HAMMER.

air enters in the direction of the arrows in the cut and into the annular section of the cylinder and piston, lifting the piston to the top position of the stroke, when the piston ports open to the annular chamber and the full air pressure is thrown against the piston.

The diameters of the four smaller sizes of pistons are respectively $1\frac{1}{4}$ and $1\frac{1}{2}$ inches; stroke, $\frac{1}{2}$, 1, and 2 inches; weight, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$ pounds, making from 1,500 to 2,500 strokes per minute. From the known weight of the piston, length of stroke, and number of strokes made per minute, the force of the hammer blow may be computed by formulas given on another page.

Although these hammers, with their smaller-sized pistons, when compared with a machinist's hammer or the mallet of the stone-cutter, seem very light for effective work, yet their light weight is in a great measure compensated for by their velocity

of about 30 feet per second at the moment of impact. This velocity, with a pressure of from 50 to 100 pounds behind it, produces a result that is fully equivalent to the ordinary blow from a much heavier hand-hammer.

Fig. 320 shows the manner of holding the hammer and chisel in chipping plate work. Fig. 321 is a stone-carving hammer, the form of which is required to adapt its position quickly to variable surfaces. It is held by the cylinder in one hand with the thumb on the knurled adjusting screw, while the other hand guides the chisel.



FIG. 320.—CHIPPING.

Riveters with yoke frames of various dimensions, and fitted with pneumatic hold-on, have many advantages when provided with claw compressors around the riveting hammer to hold the rivet-head hard against the plate and to keep the plates tight together by pressure of the piston of the hold-on. The claw is seen in the cut at the right around the hammer, Fig. 322.

When the riveter is placed over a rivet, the air valve at the left in the cut is opened, and air pressure, which may be 200 or more pounds according to the area of the piston, pushes the head of the rivet and the plates tight against the hammer claw; then by opening the valve at the right-hand side, the hammer is operated with the full force of the air pressure.

Fig. 323 shows the method of suspending a yoke riveter for a free set in any angular position. The point of suspension is at the centre of gravity, so that the riveter is easily held in any

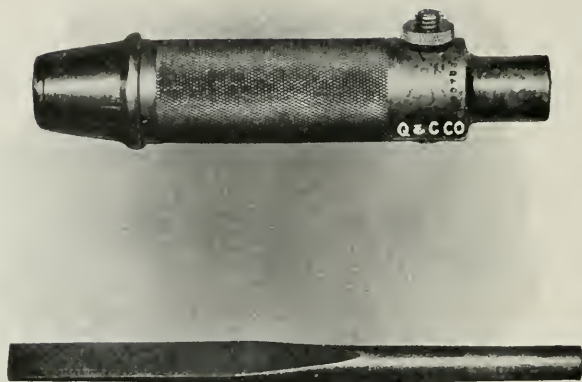


FIG. 321.—STONE-CARVING HAMMER.

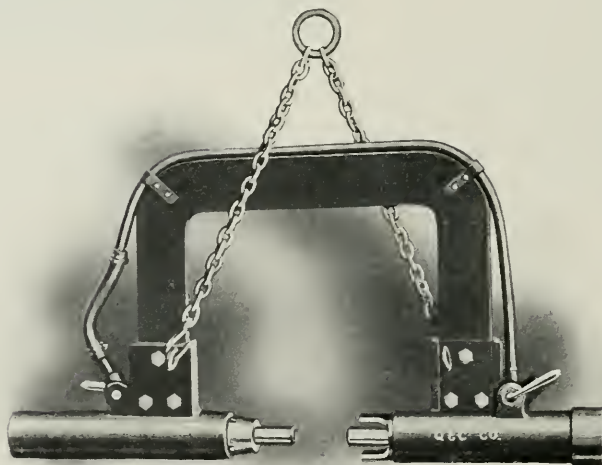


FIG. 322.—YOKE RIVETER.

desired position. In this type the cylinder of the striking hammer is advanced to catch the end of the rivet by sliding forward in the outer shell at the same moment that the ham-

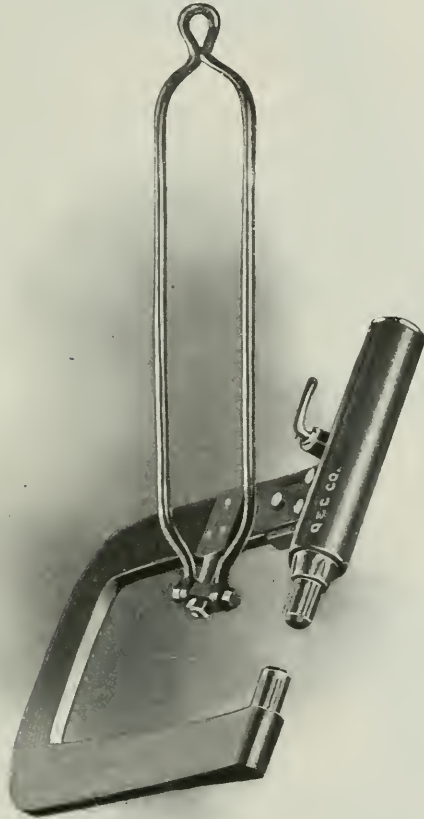


FIG. 323.—YOKE-RIVETER SUSPENSION.

mer begins to operate, and is held there by the same pressure that operates the hammer.

The bar-yoke riveter may be suspended for vertical work; it being a universal suspension arrangement by which any position may be obtained by a mere change in the socket hold. This class of riveters above 30-inch gap are made with pipe frames up to 6 or more feet gap, with varying openings from 10 to 14 inches, or more if desired.

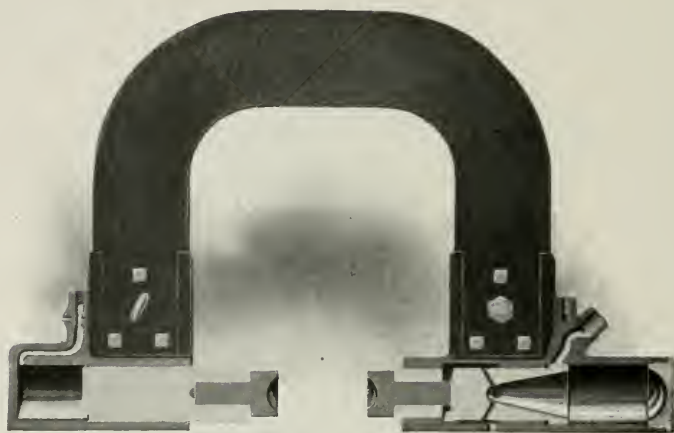


FIG. 324.—SECTION OF MOVING PARTS OF YOKE RIVETER.

The cushion hold-on.

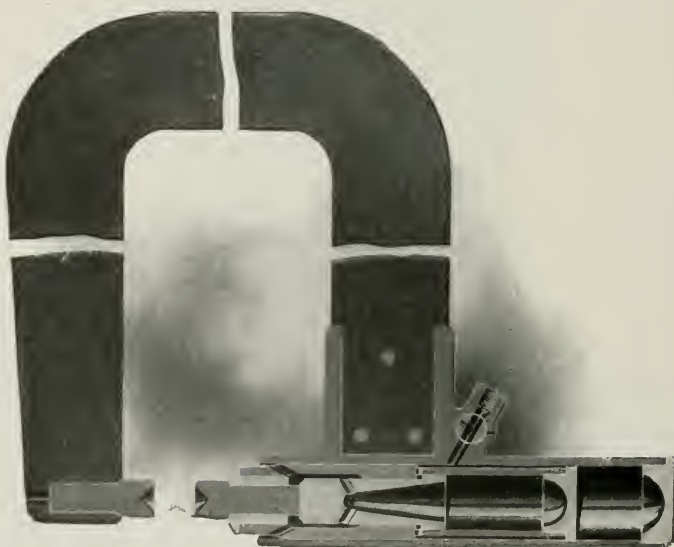


FIG. 325.—SECTION OF SOLID HEAD AND MOVING PARTS OF YOKE RIVETER (Q. & C. CO.)

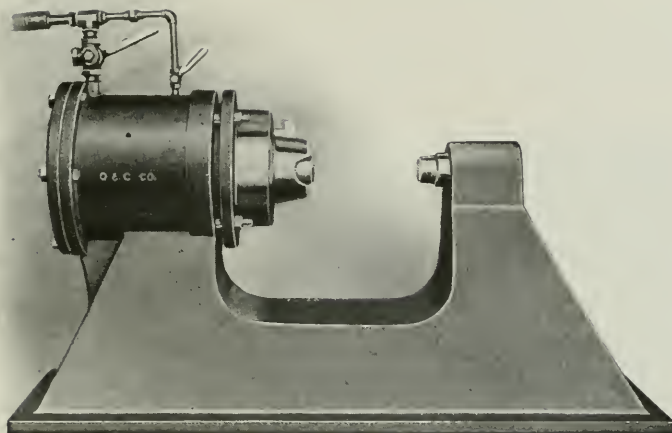


FIG. 326.—STATIONARY RIVETER.

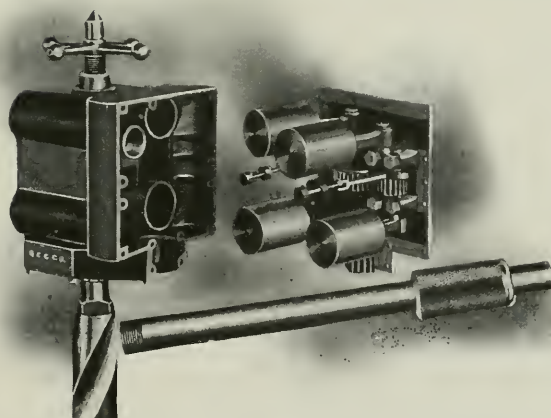


FIG. 327.—PISTON PNEUMATIC DRILL.

In Fig. 326 is represented a stationary riveter with a differential piston which closes upon the plates and rivet-head with great pressure, when the hammer piston finishes the work of riveting. The three-way valve at the left above the cylinder gives full air pressure at the back of the push piston and operates the hammer piston. By its reversion it becomes the ex-

haust port, and by opening the right-hand valve the push piston is withdrawn.

The pneumatic drills of the Q. & C. Company are illustrated in Fig. 327, showing the construction, which consists of four pistons, single-acting, connected in pairs to two crank shafts with pinions, meshed in a larger driven gear, which carries the drill. Each crank shaft operates piston valves to its pair of cylinders and is set



FIG. 328.—DRILL AT WORK.

at three-fourths cut-off. The air inlet is regulated by twisting the sleeve on the hose handle, called a rotary throttle. Two sizes are made, of 40 and 28 pounds weight, which will drill holes of $2\frac{1}{2}$ and $1\frac{1}{2}$ inches respectively.

Fig. 328 represents the reversible drill of the Q. & C. Company, for wood-boring and light metal work. It is of the same general construction as their heavier drills, but is valveless, as the pistons control the air passages. There are two spindles for high and low speeds, and by means of a special chuck the tool can be quickly changed from one spindle to the other. The drill is reversed by a small lever separate from the handle. The handle at the top can be replaced by a breastplate or a feed-screw, shown in the illustration.

PNEUMATIC TOOLS OF THE STANDARD RAILWAY EQUIPMENT
COMPANY, ST. LOUIS, MO.—HAMMERS.

The "AA" Monarch hammer has a 1-inch diameter piston. The stroke is also 1 inch, and the hammer runs at an estimated speed of 2,800 strokes per minute. Weighs $9\frac{1}{2}$ pounds and is best adapted for light calking and chipping.

The "A" Monarch hammer has a 1-inch diameter piston, the stroke is $1\frac{3}{4}$ inches; this hammer runs at an estimated speed of 2,300 strokes per minute. Weighs $10\frac{1}{2}$ pounds, and is especially desirable for general use in boiler shops and foundries, for chipping iron and steel, calking on boilers, and beading flues.

The "B" Monarch hammer has a 1-inch diameter piston, and the stroke is $2\frac{1}{2}$ inches; it runs at an estimated speed of 2,000 strokes per minute. Weighs 12 pounds. It is best adapted for heavy chipping, such as steel castings, boiler plates, and light riveting.

The consumption of air for these tools is from 15 to 18 cubic feet of free air per minute, and they operate best at a working pressure of from 80 to 100 pounds.

Their hammers are provided with a regulating valve, which enables one to use a large hammer for the lightest kind of chipping, as well as for very heavy chipping.

Great care should be taken that the working parts are kept free from grit and dirt, and the tools be kept well lubricated with a good grade of light oil.

DRILLS.

Their iron drills and wood-boring machines are all three-cylinder machines. The cylinders oscillate on one valve. The cranks have roller bearings throughout; except the spindles, which have ball-bearings. The pistons are provided with roller

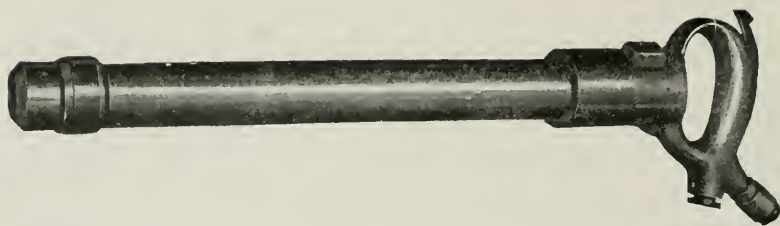


FIG. 329.—THE MONARCH LONG-STROKE RIVETER.

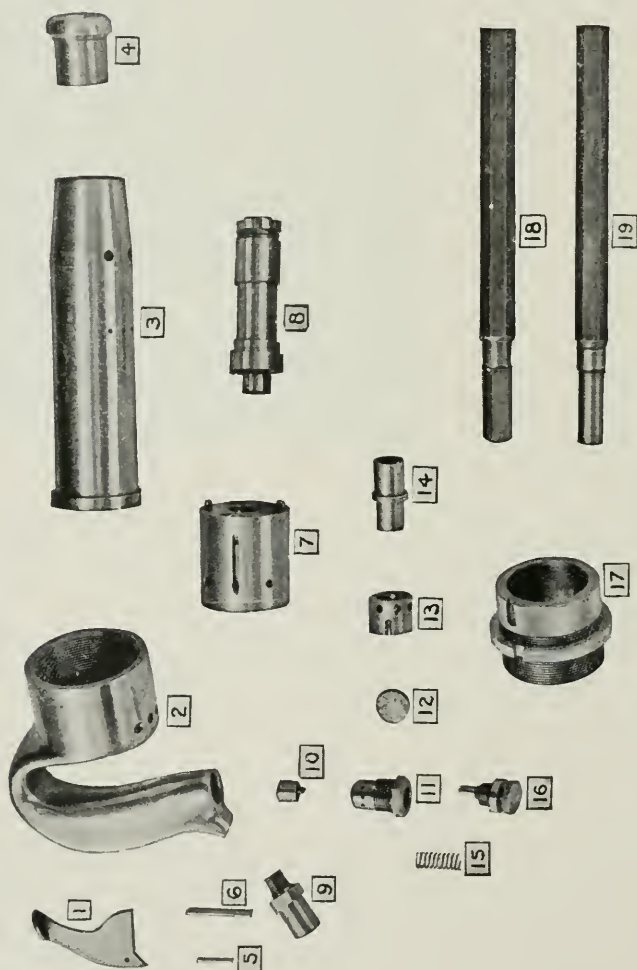


FIG. 330.—PARTS OF THE MONARCH CHIPPING HAMMER.

1, Handle trigger; 2, handle; 3, cylinder; 4, cylinder hexagon ferrule; 5, trigger pin; 6, throttle-valve pin; 7, valve block; 8, plunger; 9, strainer; 10, throttle-valve cup; 11, throttle-valve housing; 12, valve-block plug washer; 13, valve-block plug; 14, main valve; 15, throttle-valve spring; 16, regulating screw; 17, coupling-sleeve and jam-nut; 18, hexagon chisel blank; 19, round chisel blank.

bearings where they connect to the crank, which is a solid three-point crank made of tool steel, and hardened for the roller bearings. They use cut gears; the pinions are made of tool steel and hardened. The wood-boring machines are made reversible, the reversing throttle and starting throttle being in one piece and also forming part of the hose connection. The Monarch drill No. 4, which is a combination drill, and can be used for either wood-boring or iron-drilling, can be made reversible, by sliding a small screw on the throttle valve. This

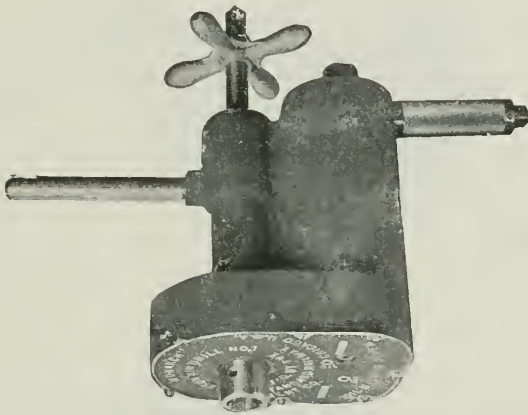


FIG. 331.—MONARCH PISTON AIR DRILL NO. 1.

drill is especially desirable for expanding flues and for tapping purposes.

The No. 1 Monarch drill has a capacity for drilling and reaming up to $2\frac{1}{4}$ inches in diameter in any kind of metal, and is economical in the consumption of air, only consuming about 20 cubic feet of free air per minute; it weighs but 32 pounds, and runs about 250 revolutions per minute. It can be used within three inches of a corner, and measures 14 inches from end of feed screw to end of spindle. All the gears and working parts are well protected from dirt, and all moving parts can be oiled while machine is running.

The Monarch No. 4 drill is built on the same principle as all of this company's drills, having three cylinders with a solid

three-way crank made of tool steel, to which the three pistons are attached, with roller bearings in each crank connection.

This machine will drill a hole up to $1\frac{1}{2}$ inches in any kind of metal; it makes about 375 revolutions per minute, consuming about 18 cubic feet of free air per minute. It weighs 20 pounds, and is arranged so that it can be made reversible by simply pushing a small button in or out on the throttle valve. This drill is especially desirable for stay-bolt tapping, reaming,

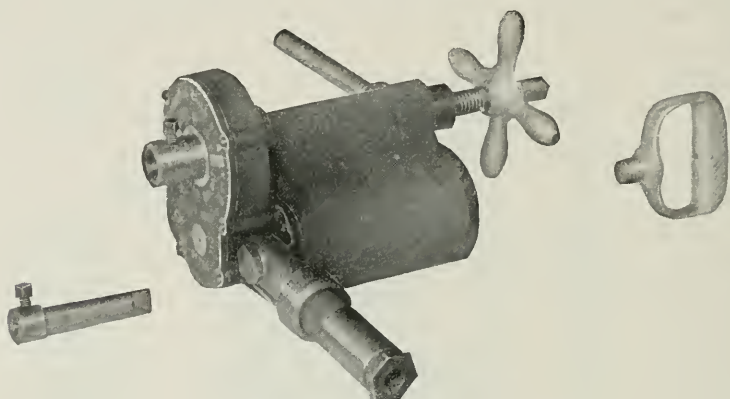


FIG. 332.—MONARCH DRILL NO. 4.

expanding flues, and for various other purposes. By taking the feed screws off and substituting a handle it can be used as a wood-boring machine.

PNEUMATIC TOOLS OF THE PHILADELPHIA PNEUMATIC TOOL COMPANY, PHILADELPHIA, PA.

The pneumatic hammers of this company are made in four sizes, of 8, 9, $10\frac{1}{2}$, and 12 pounds weight, for riveting, chipping, and calking. They are made on the constructive lines of the "Little Giant," detailed on other pages of this work. Air required per minute according to size, from 10 to 14 cubic feet.

The pneumatic hold-on has an air piston and die which is held to the rivet with the force of the air pressure due to the area of the piston. The length of the cylinder and die is 12 inches, length of stroke $3\frac{3}{4}$ inches.

Chipping by the pneumatic hammer and chisel is vastly ahead of the power of human muscle for effective work. Our illustration (Fig. 335) shows what can be done with a No. 3

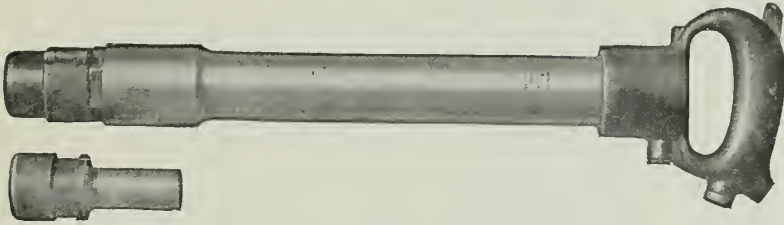


FIG. 333.—THE RIVETING HAMMER.

hammer and chisel in rolling up the chips on a strip of $\frac{3}{8}$ -inch boiler plate at the rate of 1 foot per minute, using air at 80 pounds pressure per square inch.

Chipping of any kind, whether on wrought or cast iron, steel, or even the softer metals, is a drag life to the mechanic, who can find relief from the irksome task only by stopping the slow and tedious work to rest his weary muscles; but when he can



FIG. 334.—PNEUMATIC HOLD-ON.

roll off a big chip at the rate of a foot a minute by air power, the mechanic art becomes a pleasant pastime.

We illustrate in Figs. 336 to 338 the foundry air tools of the Philadelphia Pneumatic Tool Company: the light sand rammer operated by an ordinary pneumatic hammer, a special



FIG. 335.—FAST CHIPPING.

double-handle rammer, and an adjustable rammer for suspension from a crane.

Power rammers for heavy work in foundries are comparatively recent innovations, and from their simple construction and the enormous amount of work that they will accomplish they are being rapidly adopted in this country and in Europe.



FIG. 336.—LIGHT RAMMER.



FIG. 337.—TWO-HANDLE RAMMER.

By the use of these machines one man can readily do the work of from eight to twelve men. All he has to do is to direct the blows of the rammer, moving the machine about over the work by means of the handles.

These rammers use air at a pressure of about 80 pounds per square inch, and strike from 250 to 300 blows per minute. The air supply is absolutely under the control of the operator, and he can thus regulate the force of the blow to the utmost nicety, and start and stop the rammer at will.

The light pneumatic rammer is similar in construction to the heavier type of pneumatic rammers, but still is light enough to be easily handled by the operator. It is at the same time sufficiently heavy for its inertia to absorb any vibration that may arise from the rapid reciprocation of its piston and rammer head. The valve mechanism and parts are as simple as is consistent with smooth working, and are suitably enclosed and therefore free from dust and dirt. The rammer head is a hexagon and can be turned at the will of the operator. The weight of this tool is 45 pounds, and it strikes 250 to 300 blows per minute, with an air pressure of 50 to 100 pounds per square inch, only 15 cubic feet of free air per minute being used when in continuous operation. The air is admitted to the handle on the right side, its admission

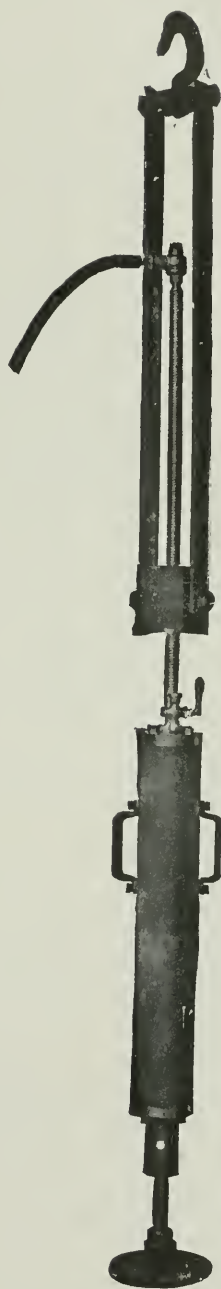


FIG. 338.—SUSPENDED RAMMER.

being controlled by a throttle lever under the thumb of the user; the exhaust passes through the handle on the left. Speed and force of the blow can be varied at will. A number of different-shaped heads are provided with each machine. These are attached to the rammer rod by means of a taper fit, and may be changed in less than half a minute and without letting go of the handle.

The constructive features of the hammers and rammers of this company are based on the Keller patents.

THE COUNTERBALANCED SAND-RAMMER IN FOUNDRY WORK.

In Fig. 338 is represented one of the modern adjuncts of a foundry for the saving of the severe labor of ramming large moulds. This sand-rammer is accurately counterbalanced and weighs with its complete rig nearly 300 pounds. It is operated by air pressure of about 40 pounds per square inch, and will deliver 300 blows per minute.

The maximum stroke is 7 inches, and the intensity and length of stroke may be varied at the will of the moulder by simply altering the distance of the rammer from the sand.

THE PNEUMATIC SAND-SIFTER.

The meagre mechanism of the foundry has lately received an important addition in the machine illustrated in Fig. 339. It is a sand-sifting machine, operated by compressed air. It consists of a heavy oak frame, containing a swinging riddle or sieve, that can be removed by simply lifting it out of the frame when necessary to use a sieve of different mesh. The motive power is a substantial balanced rotary motor of the Chicago Pneumatic Tool Company, which drives the gear connected to the three-pointed knocker attached to the sieve. Foundries which are using these machines state that they not only cover their cost in a short while by economy in labor, but that the tempering of the sand can be done much better than by hand.

One of the numerous special employments of compressed air in foundry work is the revolving steel brush for cleaning castings, operated by a rotary air motor. It finds many places for

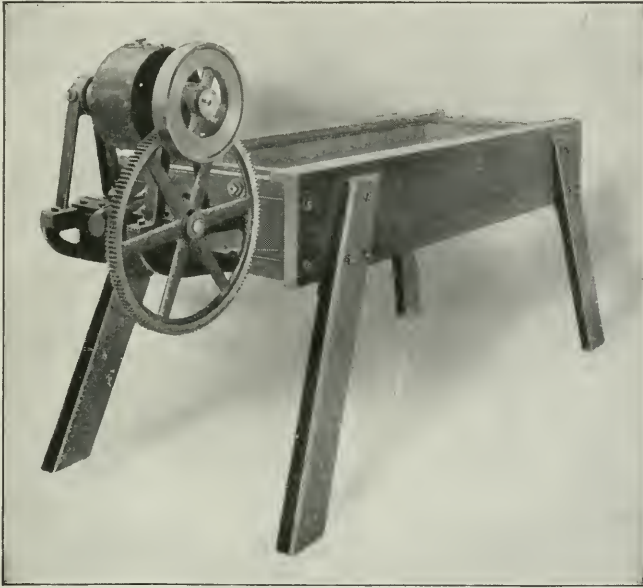


FIG. 339.—PNEUMATIC SAND-SIFTER.

useful work where the sand blast is not available, especially for inside cleaning after cores and moulding sand have been removed. These, with the many other applications of special air-driven tools noted in this work, suggest the inevitable conclusion that, when once you have compressed air available, the number



FIG. 340.—PNEUMATIC CASTING CLEANER.

of convenient and economical possibilities that it presents to the progressive operator is surprising, and its field of service broadens with amazing and gratifying rapidity.

THE MOULDING MACHINE IN THE FOUNDRY.

One of the best labor-savers in the foundry is the pneumatic moulding machine. The early forms of small flask moulding machine required shafting, belts, and gears to operate them, which are not always convenient in a foundry moulding-room.

The pneumatic system requires only a compressed-air pipe from the source of compressed-air supply in the main works

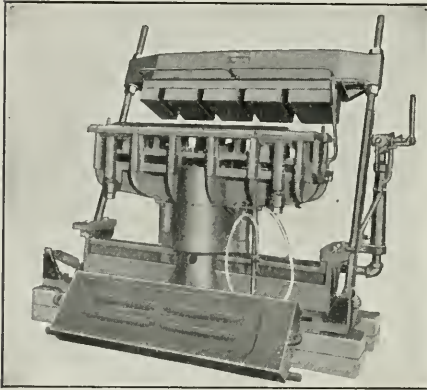


FIG. 341.—PNEUMATIC MOULDING MACHINE.

with connections, when the machine is ready for work. The machine is constructed on the lines of a hydraulic lift, except that the pressure piston is operated by direct air pressure of from 75 to 80 pounds, as used in the operation of other pneumatic machines and in machine and constructive works.

The upper platen is adjusted and fixed in its working position by tie rods jointed at the bottom of the machine, by which it can be moved off from over the flask for filling with sand, and removing patterns and flask. The lower platen carrying the flask moves upward by the air pressure in the cylinder and compresses the sand by a weight equal to several thousand pounds, merely by turning a three-way cock as shown at the right-hand side of the cut. After ramming, the head is pushed back, and the match and drag are turned over in the usual way. The match is then removed and the cope flask is fitted over the pins; parting and moulding sand is then filled into the cope and put under pressure. A pneumatic vibrator, made on the lines of the vibrating piston in a pneumatic hammer, is attached to the flask, by which a sharp tremor is set up in the vibrating frame and patterns, when the cope and patterns may be drawn in the usual way.

The pneumatic moulding machines are made in several sizes by the Tabor Manufacturing Company, Philadelphia, Pa.

THE FLUE-WELDING HAMMER.

A most important adjunct of the locomotive shop. It is used for piecing out and welding out tubes which have been damaged by the burning of end or by removal.

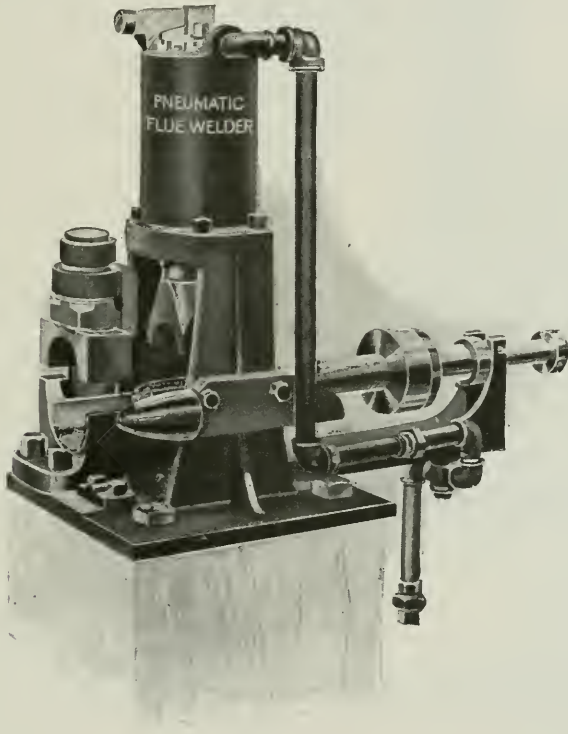


FIG. 342.—THE PNEUMATIC FLUE-WELDING MACHINE.
Chicago Pneumatic Tool Company, Chicago, Ill.

A PNEUMATIC ROCK DRILL AS A HAMMER.

This consists essentially of a drill mounted in a forged steel frame, which is suspended by the arms (shown in Fig. 343) to a frame with holding brackets; making a rig that can be handled with ease, and doing the work required in less time and at a lower cost than has been done heretofore by hand.

It has been used extensively in the construction work on the piers for the new East River Bridge, for driving drift bolts. A record of its performance there has been kept, establishing thereby another and permanent use for rock drills in a new field.

Is is a large type of the pneumatic hammer. It is the Little Giant drill of the Rand Drill Company.

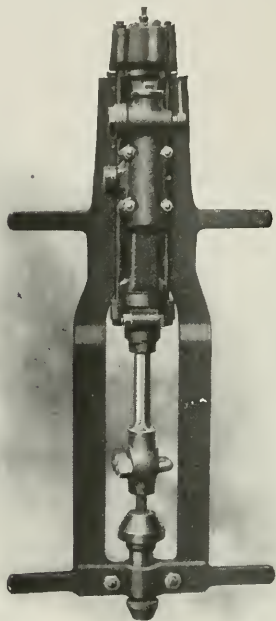


FIG. 343.—PNEUMATIC DRIFT-BOLT DRIVER.

COMPRESSED-AIR DRILLS OF
THE PHILADELPHIA
PNEUMATIC TOOL COM-
PANY.

These are of the rotary type specified in the general description on another page, and are made in two sizes, weighing 45 and 58 pounds, and using 35 cubic feet of air per minute for full service. The small size will drill a $1\frac{3}{4}$ -inch hole in steel, while the larger size has a capacity of

drilling a 3-inch hole in steel, with 80 pounds air pressure. It is a powerful all-round machine for drilling, reaming, tapping, and stay-bolt screwing. The motor blades are fitted with metallic packing which automatically takes up wear and maintains efficiency of the working parts.

AIR DRILLS OF THE STOW FLEXIBLE SHAFT CO.

In Fig. 345 is illustrated the rotary motor drill made on the lines of the patent of Caid H. Peck, No. 507,752, consisting of a rotary motor revolving on the drill spindle and reducing its speed motion to the spindle through a set of differential gears.

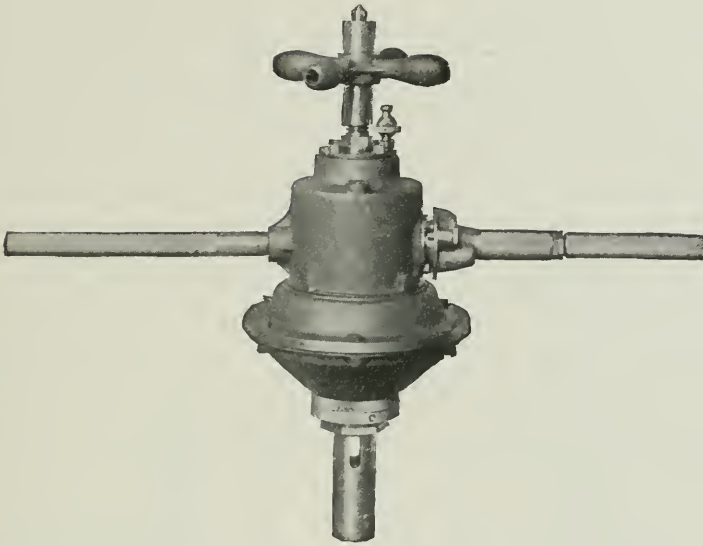


FIG. 344.—PNEUMATIC ROTARY DRILL.

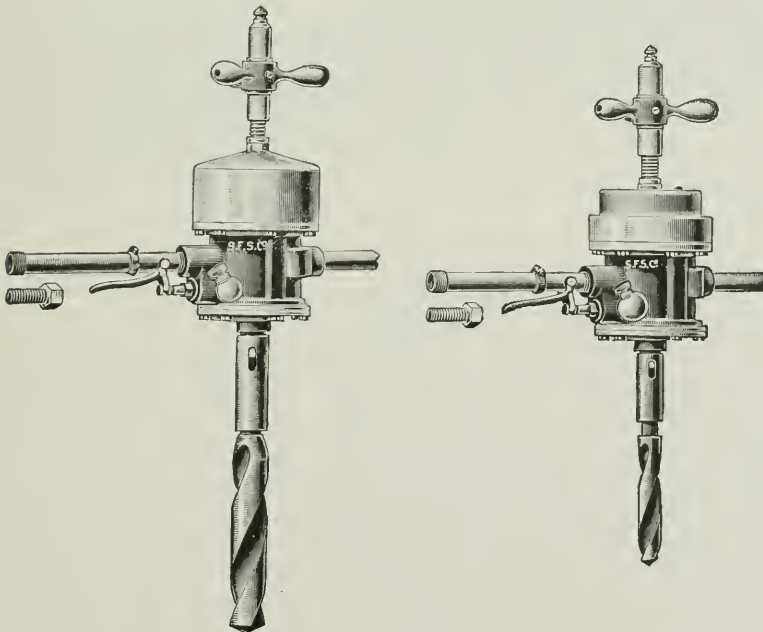


FIG. 345.—AIR DRILLS OF THE STOW FLEXIBLE SHAFT COMPANY, PHILADELPHIA, PA.

Air is admitted through one handle by the lift of the valve lever, into the inside of the piston, and is forced out through holes directly against the vanes; this starts the piston to revolving, and when it gets around to the other handle this air has done its work and is exhausted.

The motion of the piston is transmitted through the double sun-and-planet gears in the gear case to the spindle, and the speed of this spindle is regulated by the number of gears. In what is called the single-gearred machine, as illustrated in the right-hand figure of the cut, the speed is reduced to one degree,

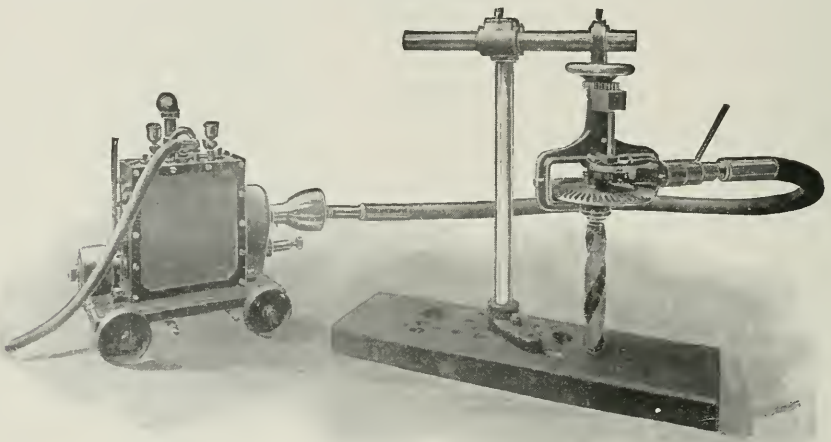


FIG. 346.—AIR MOTOR OPERATING A DRILL WITH A STOW FLEXIBLE SHAFT.

while in the double-gearred machine there is a second set of gears, and the speed is only half as great.

The air motor is composed of a pair of cylinders, oscillating on centres, taking air from a cylindrically faced air chest, through suitable passages and ports, and giving motion to the crank shaft. This is the strong point of the machine; it is made from the solid forged steel, and will stand all the work that can be put on it safely. The normal speed of about 1,200 revolutions is reduced by a set of speed-reducing gears in the case at one end, and the other end has a small balance-wheel and a lever for starting or for slowly working by hand if necessary.

AIR DRILLS AND HOISTS OF THE EMPIRE ENGINE AND MOTOR COMPANY, ORANGEBURG, NEW YORK.

The drills of this company are made in five sizes, having a capacity for drilling in metal from $\frac{3}{16}$ to $1\frac{1}{2}$ -inch holes. They are driven by a horizontal rotary motor with a pinion meshing into two intermediate gears, and they into an internal gear rack, which is stationary, being held in place by the cylinder head. The two intermediate gears are placed radially on the arms of the spindle, which travels with the gears, thereby equalizing the strain on bearings and making friction light.

The air-motor hoists of this company are illustrated in Figs. 349 and 350. They are operated by a rotary motor containing two blades in an eccentrically located piston as shown

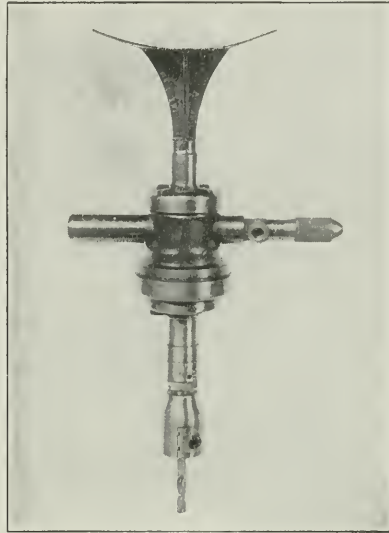


FIG. 347.—BREAST DRILL.

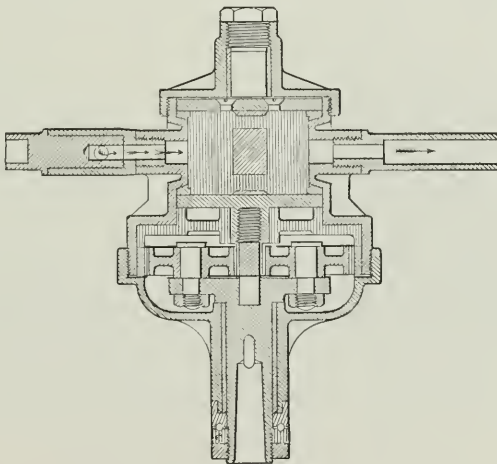


FIG. 348.—THE ROTARY MOVEMENT.

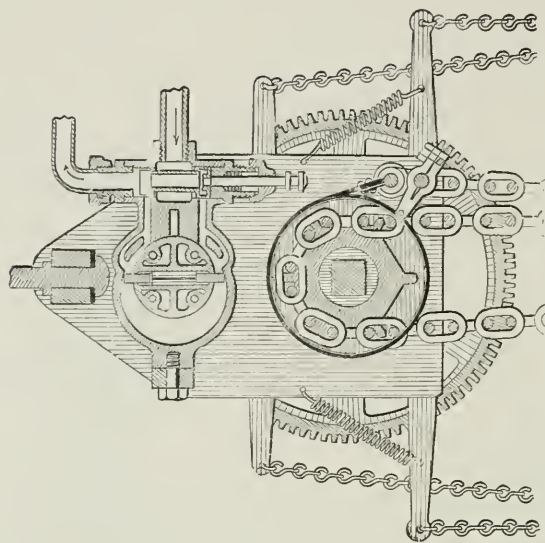


FIG. 350.—MOTOR AND CONNECTIONS.

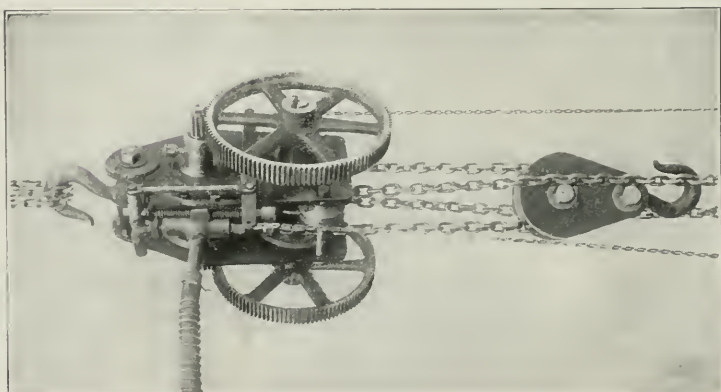


FIG. 349.—ROTARY HOIST.

in the detailed cut, and geared by double pinions to large gear wheels with differential chain sheaves on the main shaft. They do not depend upon air pressure to sustain the load, being provided with a brake. They are also made to run on a suspended trolley or boom of a jib crane.

PNEUMATIC TOOLS OF THE C. H. SHAW PNEUMATIC TOOL
COMPANY, DENVER, COLO.

The tools are very simple in their construction, yet efficient for work. The chipping and calking hammer is made up of six



FIG. 351.—THE ECLIPSE HAMMER.

pieces and is so simple in form that any machinist can renew the parts liable to wear. It has a spring handle and is valveless in the operating parts, the admission air valve being operated by the grasp of the handle.

The marble-cutter's hammer is equally simple in construction; it has a compression air valve operated by the pressure of

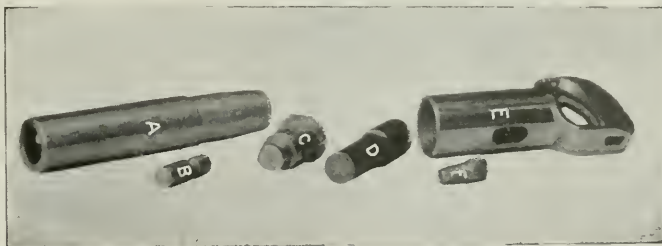


FIG. 352.—PARTS OF THE ECLIPSE HAMMER.

the thumb, and also a screw regulating valve to regulate the air pressure for very light work. Usual air pressure, 30 to 50 pounds for marble work.

The two-cylinder compound air drill of this company is illustrated in Fig. 354. The arrangement of the pistons and

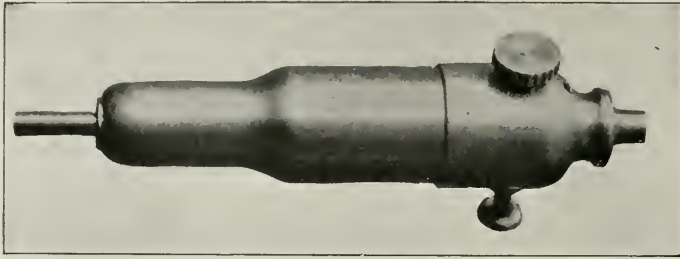


FIG. 353 —THE MARBLE CUTTER'S HAMMER.

connections is such as to allow of no dead centre, and the compounding of the cylinders carries the exhaust nearly to atmospheric pressure. A more powerful drill, having four cylinders, is manufactured by the same firm. This company also makes a single-cylinder rotary drill or tapping machine with a four-bladed piston having no dead centre or weak place in its revo-

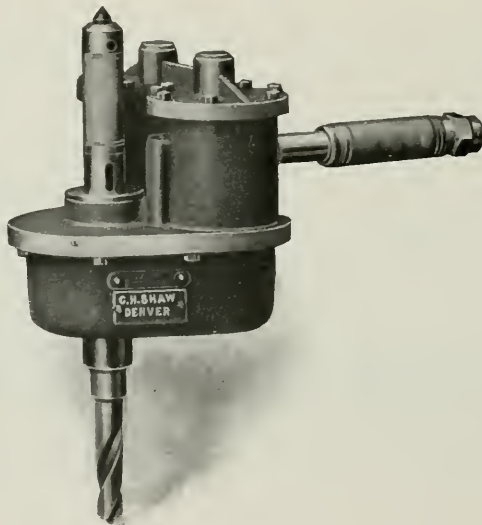


FIG. 354.—COMPOUND AIR DRILL.

lution. It is made in two sizes, for drilling and tapping, up to $1\frac{1}{8}$ and $1\frac{1}{2}$ -inch holes respectively, and is very suitable for boiler work.

PNEUMATIC TOOLS OF THE AMERICAN PNEUMATIC TOOL
COMPANY, NEW YORK CITY.

The tools of this company have been long in use for metal and stone work, and are simple in design and effective in their

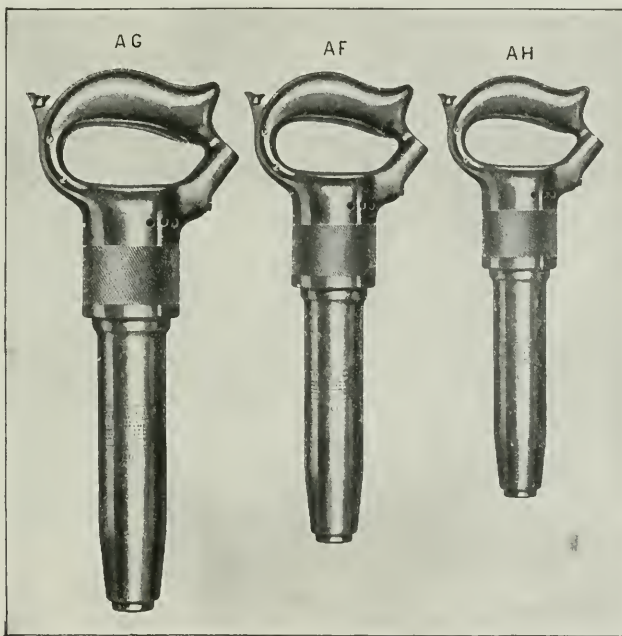


FIG. 355.—PNEUMATIC HAMMERS OF THE AMERICAN PNEUMATIC TOOL COMPANY.

working power. They are made in three sizes, for light, medium, and heavy work.

The details of the parts of these hammers are as follows: the handle and valve-seat case screwed upon the cylinder, the valve block or seat containing the air passages, and the valve spool which operates automatically in the valve block, the piston, and tool bushing.

The stone-dressing pneumatic tools of this Company are here illustrated in four sizes, of which the A size is a very light tool for tracing and small lettering; the BX size is for heavy lettering and carving, and the other two are for heavier cutting and roughing.

The lighter tools are for lettering and finishing. In this class the piston contains the automatic valve, and part of the

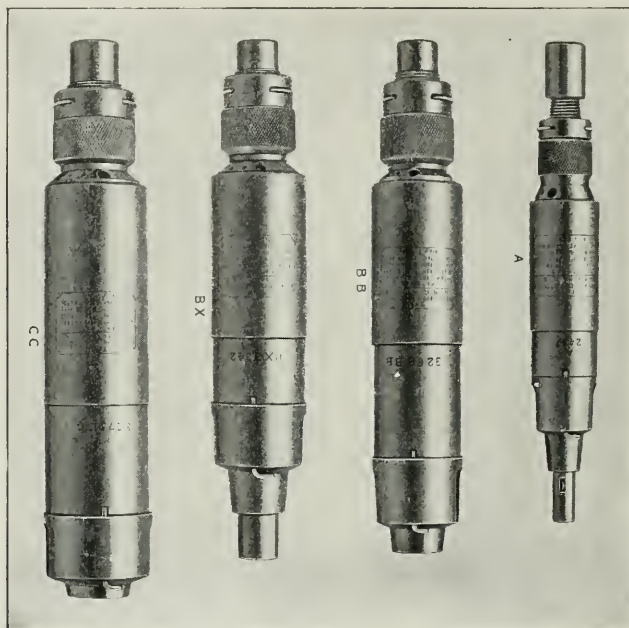


FIG. 356.—STONE-DRESSING PNEUMATIC HAMMERS.

exhaust opens at the nose of the tool to blow away the chips and dust.

The detailed parts are shown in Fig. 357. 1 is the cylinder screwed to the nose-piece 7, and covered by a jacket 4. The piston 5 is perforated across the centre and contains the spool valve and internal ports and air passages for operating the piston, their counterpart being through the walls of the cylinder, communicating with the inlet and exhaust passage shown under the jacket. The throttle sleeve, 3, regulates the air flow by controlling the exhaust; 6 is a bumper washer, fixed by the

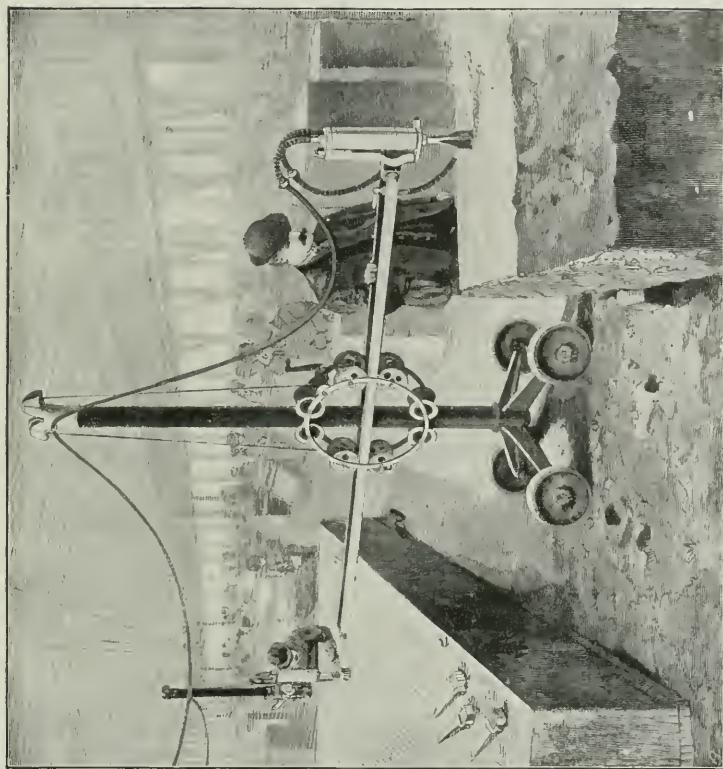


FIG. 358.—PNEUMATIC STONE-DRESSING MACHINE.

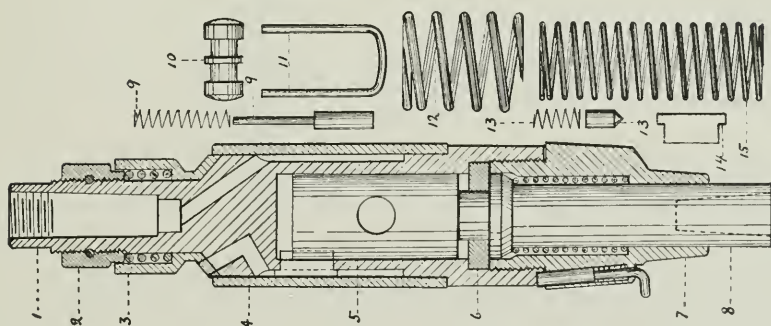


FIG. 357.—TOOL PARTS.

shoulders of the cylinder and nose-piece. The tool-holder is held back against the washer by a helical spring, 15; 11 is a U-shaped wire to keep the throttle nut 2 from turning; 12 is a helical spring to keep the throttle sleeve to its conical bearing; 14 is a spline shown at the top of the piston and fixed in the cylinder to keep the piston from revolving and displacing the air ports. This company also makes a valveless stone hammer equal to all the requirements of light stone-cutting and lettering, and containing but few working parts in its construction.

The pneumatic stone-dressing machine (Fig. 358) is one of the most convenient and best labor-saving appliances used in a stone-cutting establishment. A hammer of the larger dimension, mounted on the end of a traveller running freely between rollers, suspended and balanced on a post resting on a truck, is a rig that gives complete control of the motion of the tool over the face of a block of stone. The hand easily guides the tool

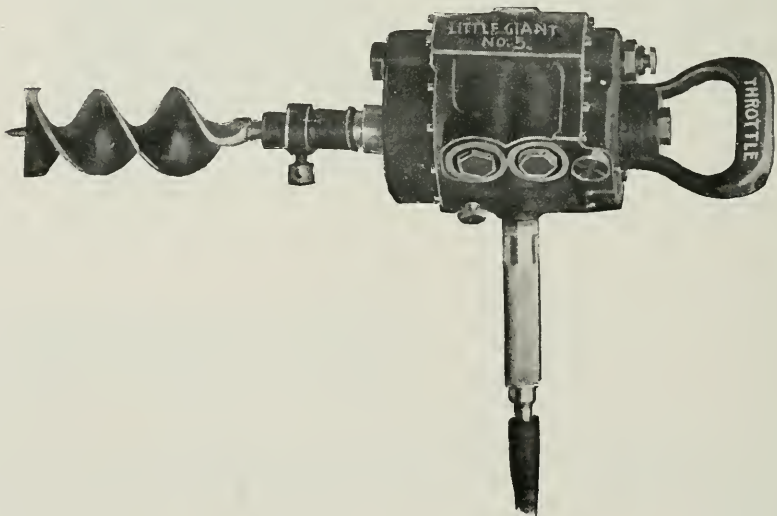


FIG. 359.—LITTLE GIANT AIR DRILL.

for evening the surface and for hammer dressing, a most tedious operation when done by hand. The exhaust is at the top of the tool cylinder and is directed toward the cutter by

a hose, thereby keeping the face of the stone clear of chips and dust for the inspection of the workman.

AIR TOOLS OF THE STANDARD PNEUMATIC TOOL COMPANY,
CHICAGO, ILL.

We illustrate in figs. 359 and 360 the "Little Giant" reversible piston type air motors, used for all kinds of portable drilling, reaming, and tapping in the machine shop and in outdoor

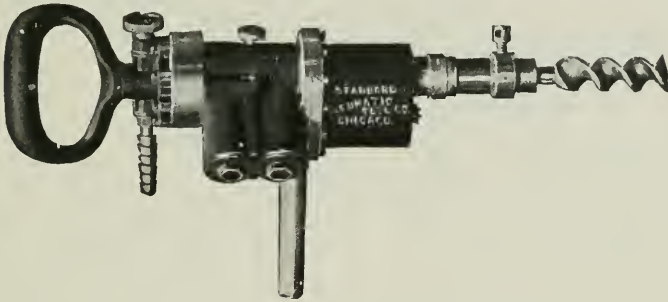


FIG. 360.—SMALL TWO-PISTON MOTOR DRILL.

practice. The motor consists of four single-acting cylinders, in pairs, connected to opposite ends of a double crank shaft, so that the shaft receives four impulses at each revolution, and develops from $1\frac{1}{2}$ to $3\frac{1}{2}$ horse power, in the various sizes, at 80 pounds air pressure.

This company also makes the "Little Giant" pneumatic hammers, air hoists, motor chain hoists, air car-jacks, stay-bolt nippers, and yoke riveters.

COMPRESSED-AIR RIVETERS.

Direct-pressure riveters are used as stationary machines for riveting boiler and tank shells. Their large pistons act directly upon the rivet, and they are quick-moving powers for this work. The toggle-joint movement with small piston and cylinder mounted on a portable frame has become the general type for structural work. The Allen yoke riveter is one of the types in which the toggle joint is pivoted to a cam bar and also within

the trunk piston. By the differential or trunk form of piston the return stroke economizes the compressed air, while the large piston area gives great power to the riveting stroke.

A double-lever riveter is sketched in Fig. 362, in which the air piston acts directly upon the toggle joint by drawing it toward the cylinder. It is balanced on a yoke.

These sketches are from the early models of the Allen patents. These riveters have been in practical operation for many years as standard pneumatic tools. They have been remodeled

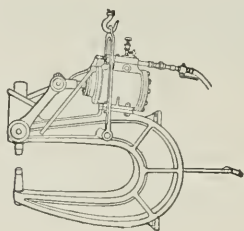


FIG. 361.—ALLEN MODEL.

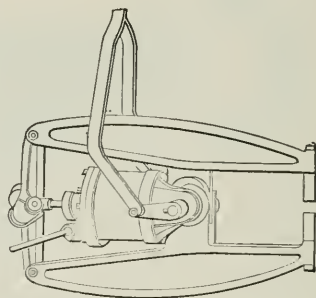


FIG. 362.—DOUBLE LEVER RIVETER.

and improved to meet the requirements of all kinds of structural work, until there seems to be no place that a pneumatic riveter cannot reach, as shown by accompanying illustrations.

PNEUMATIC RIVETERS OF THE CHESTER B. ALBREE IRON WORKS, ALLEGHENY, PA.

The riveters of this company are of the toggle-joint type, giving the theoretically correct pressure due to the increasing resistance of the rivet during the driving stroke. A connecting bar holds the thrust member of the rolling toggle to prevent binding of the rivet piston, which is drawn back by a helical spring. A screw on the riveting die serves for adjustment of throw. A special design is shown in Fig. 363 for riveting columns, as the horn can be inserted between the channels and braces. Fig. 365 shows how easily the riveter may be inverted with the aid of the universal bail.

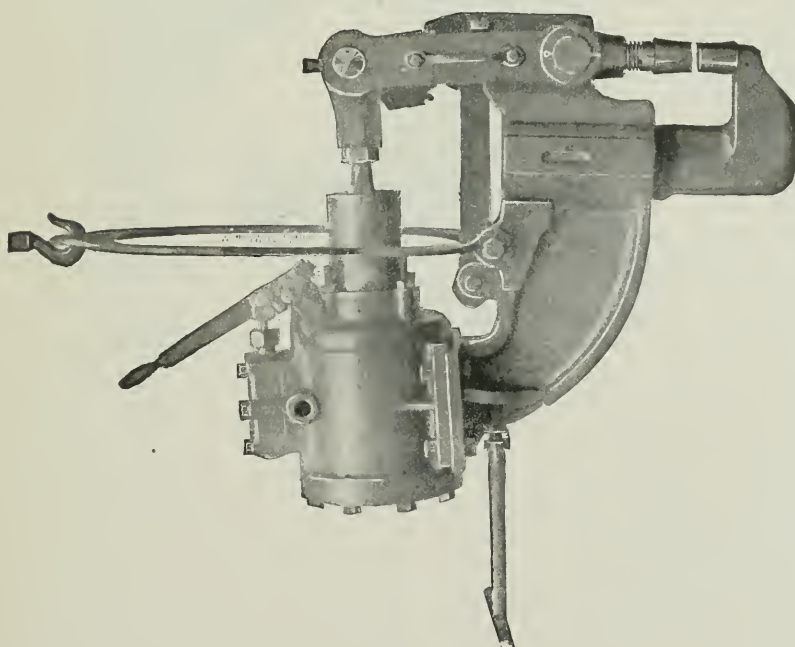


FIG. 369.—THE PITTSBURGH COLUMN RIVETER.

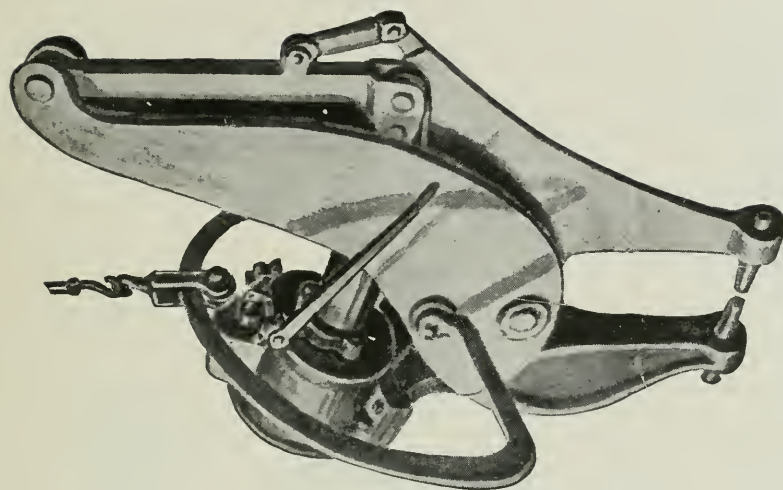


FIG. 364.—PITTSBURGH NIPPER RIVETER
On a universal hanger.

AIR HOISTS.

The application of air hoists to cranes, over-lathes, planers, drilling machines, and, in fact, to all conditions in which a hoist may be useful, is now made in an almost endless variety of ways to meet the requirements of machine shop and foundry

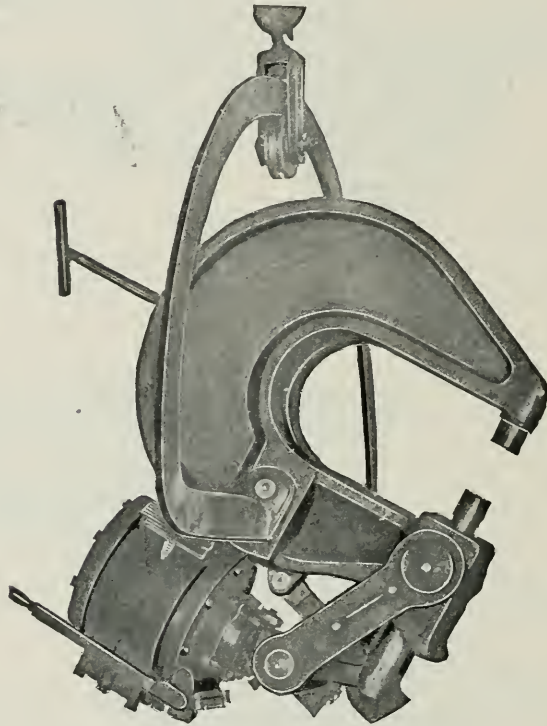


FIG. 365.—INVERTED ON UNIVERSAL BAIL.

practice. The most common type is the simple cylinder hoist, either vertical or horizontal, or in combination with an intermediate inelastic fluid, water or oil.

In many instances direct-acting hoists may be readily applied to hand-power cranes already in use, in which the hoist may be hooked to the gear tackle for adjusting the height, when the air hoist may be used for quick work.

In Fig. 366 is shown the safety stop applied to the direct hoist for arresting the lift automatically at any desired point by closing the air valve, the lift being otherwise controlled by the three-way cock and double lanyard.

THE OIL-GOVERNED PNEUMATIC HOIST OF
THE CRAIG RIDGWAY & SON COMPANY,
COATESVILLE, PA.

The top head is enlarged to form a reservoir. To this head is secured a bar which has a pas-

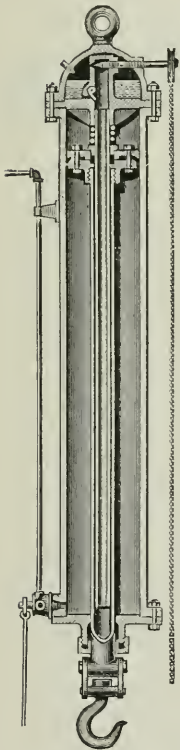


FIG. 367. — OIL-GOV-
ERNED HOIST.

sageway through it connecting with the reservoir. This fixed bar passes through the piston and enters the hollow piston rod. A leather cup supplemented by any ordinary packing-box makes a tight working-joint at the piston with the fixed bar. In the reservoir are two valves, one a swing check valve and the other a simple regulating valve with a screw stem. The stem extends outside the reservoir and is provided with a sprocket wheel for regulation.

The action of the governing device is as follows: The piston is pulled down to the end of its stroke and ordinary machine oil is poured into the reservoir. It passes the valves and fills the hollow piston rod. If now full pressure of air be under the piston and the valves be closed, the hoist cannot move, its movement being resisted by the fixed bar and the oil in the hollow rod. If now the regulating

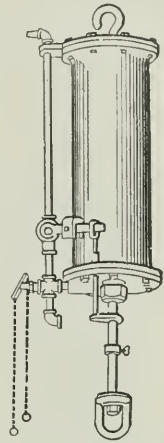


FIG. 366. — SAFETY
STOP AIR HOIST.

valve be opened, the oil will escape into the reservoir, and the hoist will rise just as fast as the oil can pass this valve, and no faster. It makes no difference how the air is admitted to the

hoist, or whether the hoist is loaded or empty, its motion is controlled entirely by the oil. When the piston lowers, the oil passes back into the rod by the check valve.

An air inlet valve is also connected with the upper and the under side of the piston. The under side of the piston is always connected to the compressor and always under pressure; the oil pan is also always under pressure. The valve admits air to and exhausts from the upper side of the piston. No air is consumed in lifting the load, the air being used to press the piston down the cylinder. The air being admitted above the piston,

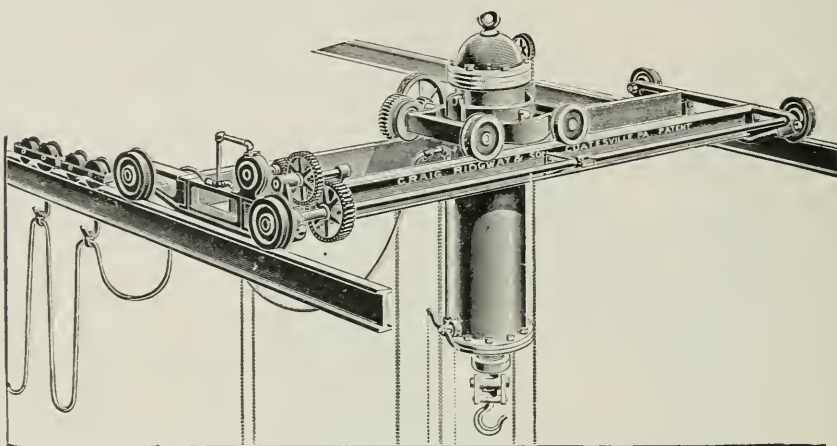


FIG. 368.—TRAVELLING CRANE AND AIR HOIST.

pressure is equalized on both sides and the piston is forced down the cylinder with a force equal to the diameter of the piston rod. The oil is forced into the rod by pressure. Gravity is not depended upon to lower the piston, and packings can be made and kept tight. No air from the shop ever enters the cylinder to carry in dirt and dust. All motions being under perfect control, and all done by pressure, jerkiness and danger are entirely overcome. The air pressure, being always under the piston, is like a big perfect spring; and with the oil to regulate its upward motion, the Ridgway hoist reaches a high point of perfection.

TRAVELLING CRANE WITH AIR HOIST.

The Ridgway air hoists are mounted in many ways to suit the wants of foundries and machine shops. The most common plan is to carry them upon travelling bridges, swing cranes, or runways. The cut shows a ten-ton hoist upon a traveller. The cylinder is hung in a gimbal truck, and is moved back and forth on the bridge by a pendant hand chain. The bridge is travelled by an air engine, operated by cords from the floor, or it may be arranged to move by hand. The crane is connected to the air supply at end of the runway by a hose. The hose is carried in sections by small trucks travelling upon one of the tracks of the runway. A better plan is to carry the hose by trucks or slides upon a special track over the centre of the span. Slides are preferred by some to trucks, in that they never get out of order or need attention. As the crane travels in one direction the hose stretches out one loop after another. As it moves in the opposite direction the trucks or slides are pushed ahead and gather up the hose.

In the smaller travelling crane of two-ton capacity, the hoist is carried by a trolley running upon the lower flange of a single I beam. In this case the hose is wrapped upon a reel, the air being taken in through the hollow axis of the reel. The reel is placed so the cylinder can move past it and cover the full span of the bridge. The hose is attached to the air supply at one end of the runway. A cord is run from the reel to the opposite end of the runway. The pull of the hose unwinds it from the reel as the crane

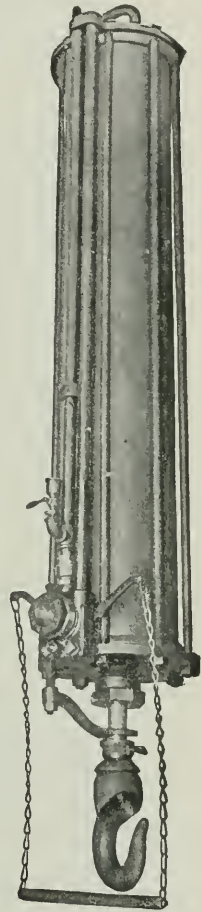


FIG. 369.—AIR HOIST.

moves in one direction, while the pull of the cord winds up the hose as the crane moves in the opposite direction.

The festoon and the reel plan are the two most approved ways of taking care of the hose. When it can be used the festoon plan will be found, on the whole, the cheapest and best of the two.

AIR HOISTS OF THE CURTIS MANUFACTURING COMPANY.

The air hoists of this company are made in eleven sizes, from 3 to 16 inches in diameter; and with standard lifts of 4 feet, or of special lengths when desired. These hoists have a special self-closing valve device, shown in the enlarged view (Fig. 370), by which a helical spring, attached by suspender chains to each arm of the valve, brings the valve to its closure independently of the operating of the hand chains.

An adjustable stop operated by a set collar on the piston rod stops the load at any set point, by moving a rack and pinion.

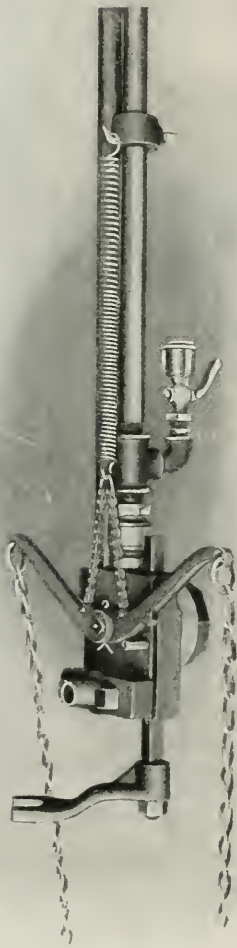


FIG. 370.—SELF-CLOSING VALVE.

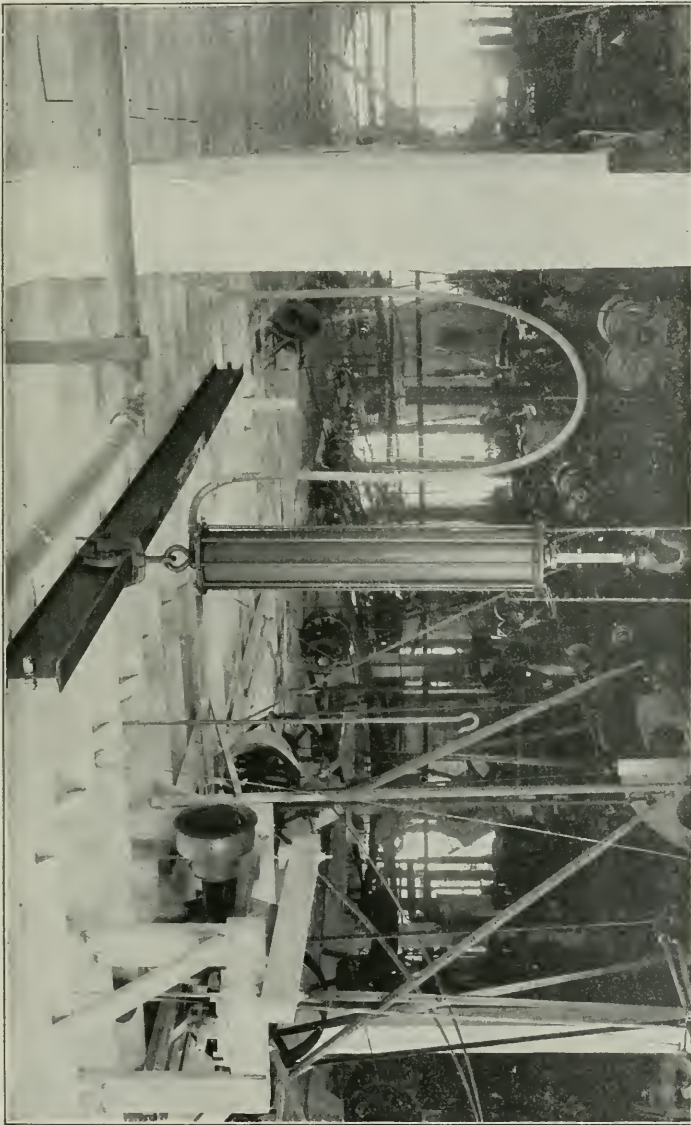


FIG. 371.—THE AIR HOIST IN THE MACHINE SHOP.
On trolley over the planers. Curtis Manufacturing Company, St. Louis, Mo.

It has also an adjustment for regulating the speed of the hoist independently of the valve movement.

THE AIR-HOIST TRAVELLER FOR STORES AND WAREHOUSES.



FIG. 372.—LOADING.

For transferring goods in a warehouse or factory, or for loading and unloading goods from trucks, nothing else has been devised that is so convenient and cheap as the air hoist. The same power that operates the elevators will compress sufficient air for the operation of these handy devices. The overhead trolley rail is readily installed and can be extended across the street or across alleyways between factories, to facilitate the dropping or picking up of merchandise or machinery directly to or from the trucks. A

boy, with this aid, can lift and convey loads that would otherwise require a gang of men. In Fig. 373 is shown a horizontal air lift installed on an overhead trolley rail, for shops or stores where the ceiling is too low to accommodate a vertical lift. With long trolley rails winding among the machinery of a factory, the air pipes may be laid around the works with outlets and hose at convenient places, which may be uncoupled when the load is lifted for long-distance runs.

In Fig. 374 is shown the arrangement of the overhead trolley track, trolley, and sheaves for holding the hose as it is run out from the reel or hose drum. An arm on the trolley truck

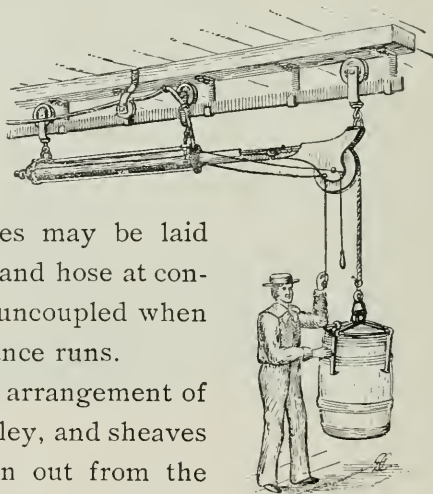


FIG. 373.—HOISTING.

allows the hose to pass over the sheaves and be drawn forward, or to be pulled back by the hose drum, which has sufficient tension to keep the hose from dropping into inconvenient loops.

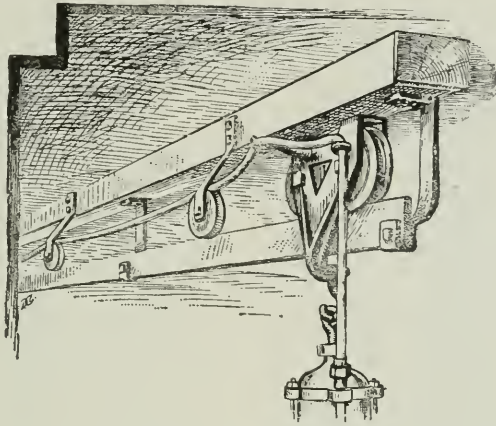


FIG. 374.—THE OVERHEAD TROLLEY AND HOSE SHEAVES.

The drum reel (Fig. 375) is counterbalanced by a weight and rope wound upon a smaller drum on the same shaft. A sprocket and chain drives a guide screw carrying a nut, frame, and sheaves to guide the winding of the hose in its proper place

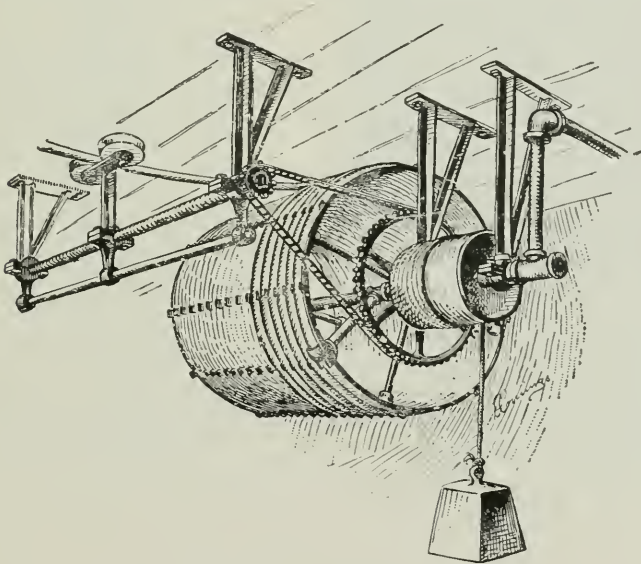


FIG. 375.—THE HOSE DRUM AND GUIDE SCREW.

on the reel. The end of the hose is connected with the hollow shaft, from the end of which a stuffing-box allows the hollow shaft to turn freely in a fitting connected to the air-pipe line from the air-compressor receiver.

The above illustrated goods hoist and conveyor is in operation at the Nason Manufacturing Company, New York City. Patent of Carleton W. Nason.

THE PNEUMATIC HOIST IN THE FOUNDRY.—AIR HOIST OF THE CHICAGO PNEUMATIC TOOL COMPANY.

In no other operation in the foundry, save the air blast, is air used to such advantage as in air hoists and cranes; and not

least in the sand rammer. By using direct-acting air hoists suspended from trolley tracks, swinging, and travelling cranes, a vast amount of heavy labor is saved. Saving is the measure of our living in these competitive times.

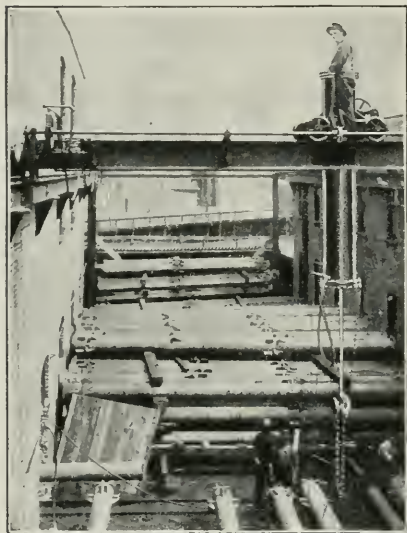


FIG. 376.—PILING AND STORING CAST-IRON COLUMNS.

With overhead trolley rails and air hoists with detachable hose couplings, castings can be readily conveyed to any part of the foundry, or outside of the building to the machine shop.

Few realize how cheap an air hoist is to operate, apart from its convenience and speed in handling loads. It has been estimated that compressed air at 90 pounds pressure costs about 5 cents per 1,000 cubic feet of free air, or 143 cubic feet of capacity in the air lift.

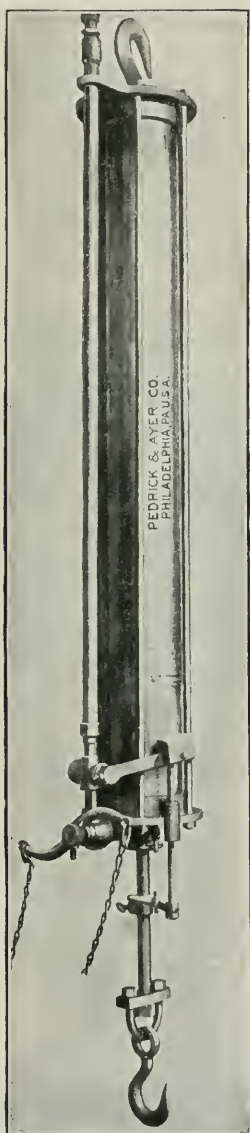


FIG. 377.—AIR LIFT, STYLE 3.
With releasing valve.

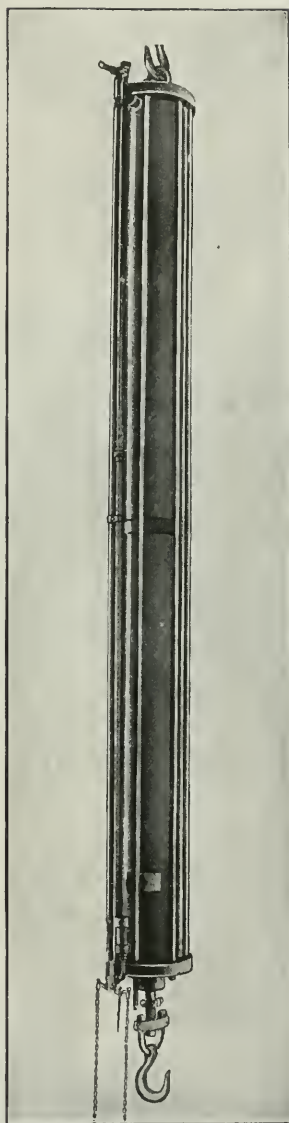


FIG. 378.—AIR LIFT, STYLE 6.
Diameter, 3 to 6 inches.

COMPRESSED-AIR APPLIANCES OF THE PEDRICK & AYER
COMPANY, PHILADELPHIA, PA.

The pneumatic lifts of this company are made with seamless hard brass tubing, with heads bolted through, and in three styles, viz.:

No. 1 style has only one valve for admitting and releasing air. With this valve, the instant the hand releases the operat-

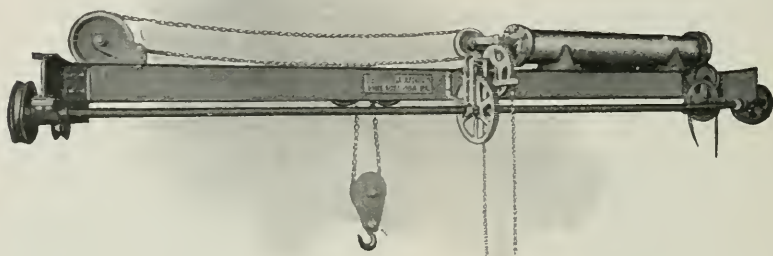


FIG. 379.—NO. 4 STYLE ON TRAVELLING CRANE.

3 to 16 inch cylinders, with any desired valve and controlling appliance.

ing chain (either when raising or lowering the load) the valve is automatically closed by the air pressure, thus shutting off the admission or discharge of the air and stopping the load at that point.

No. 2 style is fitted with two valves. One valve is for admitting and releasing the air in the cylinder and is left open to the supply when lifting the load. The second valve is con-

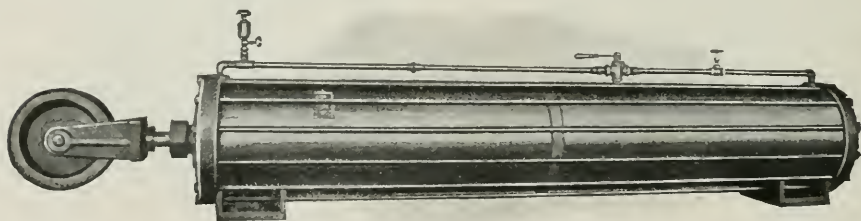


FIG. 380.—THE HORIZONTAL HOIST.

With sheaves for draw hoist, 2 to 1, for travelling cranes and boom hoists.

trolled by a loose collar with a set screw, on the piston rod, which is adjusted for the height of the lift desired. When the load is lifted to this height this second valve automatically closes, cutting off the supply of air; then, in case of leakage from any cause, it automatically admits just enough air to keep up the supply and retain the position of the load.

No. 3 style has three valves, the first two valves being identical with those of the No. 2 style, and with all their advantages, while the third valve is called a releasing valve and

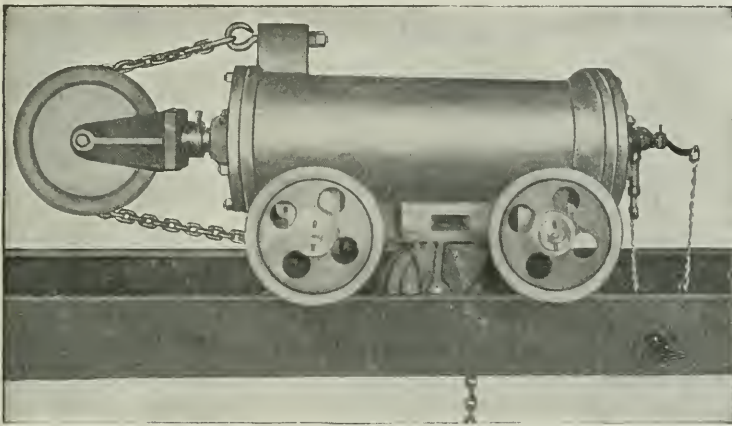


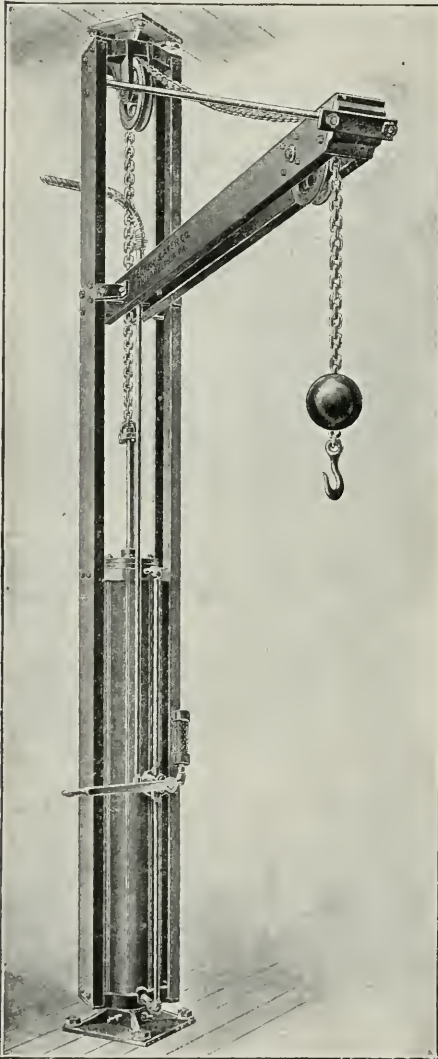
FIG. 381.—HORIZONTAL MULTIPLE HOIST
On a free running trolley for cranes and booms.

sustains the load perfectly stationary when it varies in weight while suspended, as pouring out molten metal, etc. This is obtained by the automatic action of these valves releasing or admitting air into the hoist cylinder as is necessary to keep the load in the same position.

AIR-LIFT WORK.

Diam-eter.	Capacity.	Lift.	Amount of free air consumed per 4 foot lift at 80 pounds pressure.	Diam-eter.	Capacity.	Lift.	Amount of free air consumed per 4 foot lift at 80 pounds pressure.
Inches.	Pounds.	Feet.	Cubic feet.	Inches.	Pounds.	Feet.	Cubic feet.
3	470	4	1.17	9	4,440	4	10.88
4	930	4	2.13	10	5,630	4	13.50
5	1,400	4	3.31	12	8,015	4	19.58
6	1,925	4	4.83	14	10,803	4	26.51
7	2,660	4	6.63	16	14,123	4	34.49
8	3,660	4	8.67				

The style shown in Fig. 379 is for use in foundries or in connection with sheave attachments, where the slightest movement of the hoist while suspending the load is undesirable. This is prevented by a specially arranged valve by which air is constantly on both sides of the piston, preventing jumping of the piston and giving a slow, steady movement in lowering or raising, and yet admitting of a quick movement when necessary.



THE DIRECT-ACTING PNEUMATIC-CHAIN JIB CRANE.

Admitting compressed air on the top of the piston by a valve on the back of the mast, it is forced downward and pulls with it the piston rod to which is attached a chain running over a sheave under the top pin-tle and out to the end of the jib which lifts the load. By releasing the air on top of the piston the counter-balance on end of chain falls, lifting piston into position ready to lift next load. Sheave wheels and top pin-tle of mast are furnished with roller bearings, bottom pintle of mast having ball-and-socket bearing. The height of lift is limited only by the head room; and where conditions are such that the load does not have

FIG. 382.—DIRECT-ACTING PNEUMATIC CRANE.

to be moved along the jib, this style of crane is particularly desirable on account of its simplicity.

In Fig. 383 is shown a section of the Pedrick & Ayer oil-

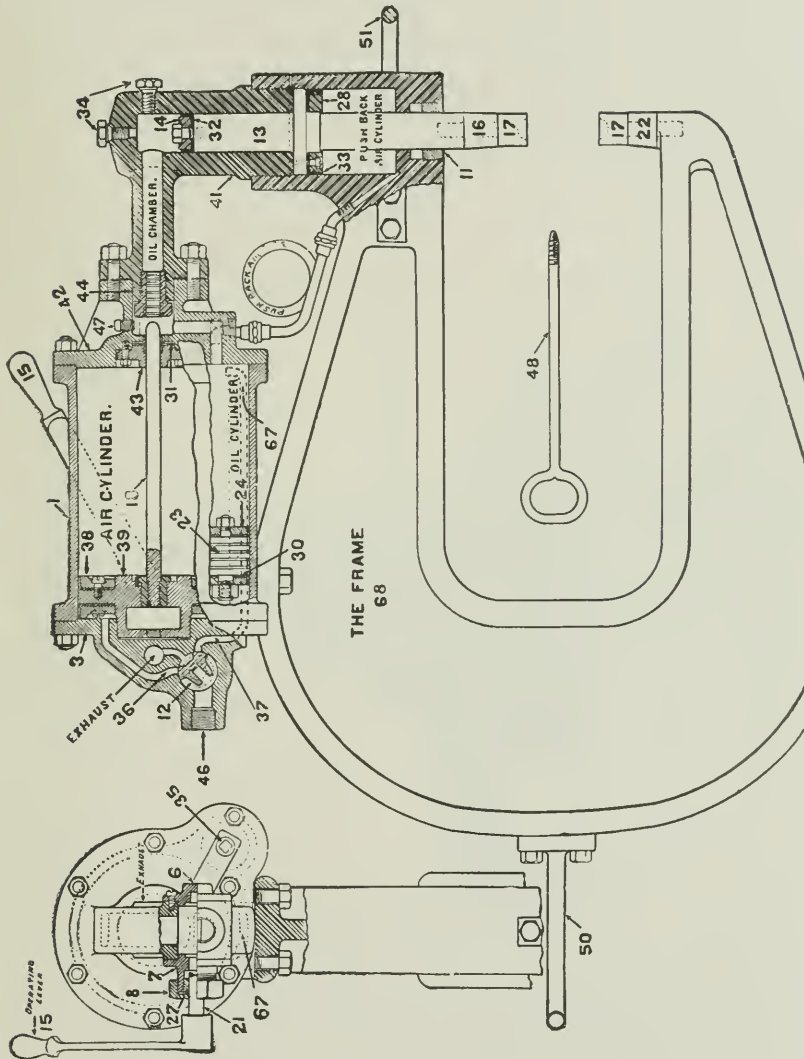


FIG. 383.—THE OIL PNEUMATIC RIVETER.

pneumatic riveter, in which by the use of differential pistons the elastic compression of air at moderate pressure controls a small piston acting upon an inelastic fluid (oil) for generating a high pressure upon the dolly-bar or riveting piston. Referring to

the sectional cut, the movement of the lever 15 operates the cylindrical three-way valve 12, for driving the piston of the air cylinder and its plunger 18, which passes through a stuffing box 44 into the oil chamber, producing a pressure equal to the differential areas of the air piston 39, plunger 18, and the dolly-bar piston 13. In this way a comparatively small air cylinder at 80 pounds air pressure may be made to exert a pressure of

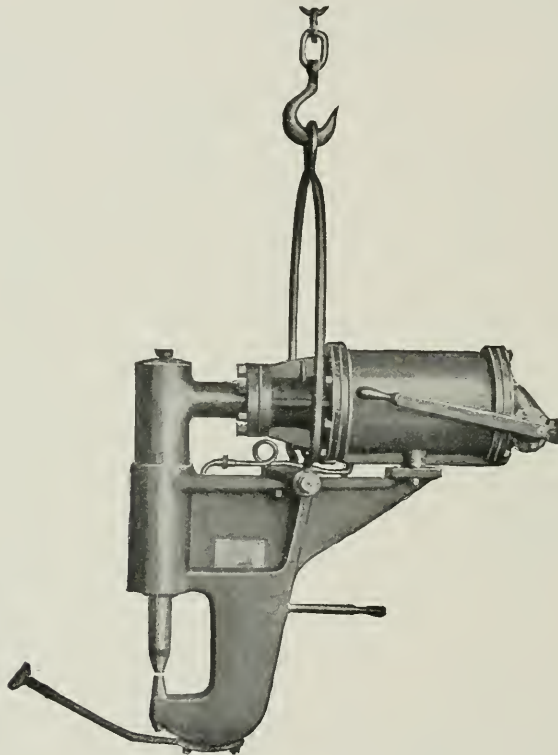


FIG. 384.—THE LATTICE OR COLUMN RIVETER.

from 10 to 15 tons on a rivet head. A free floating piston, 23, in a small separate cylinder, is made by air pressure to follow up the oil charge in the oil chamber as the dolly moves down to the rivet, and allows the oil to be drawn back by the return of the oil plunger and through the air pressure on the push-back piston on the dolly-bar 28. A rear-end view is also shown at the left, indicating the position of the oil cylinder with its

floating piston. In charging the riveter with oil, the floating piston is drawn to the back end of the cylinder by removing the plug 35 and inserting the pull rod 48.

COMPRESSED-AIR PUNCH.

In Fig. 385 is illustrated a simple and compact air punch; a most convenient and easily handled punch for sheet and plate work. It is made by the F. F. Slocomb Company, Wilmington, Del., and consists of a hollow piston adapted to contain oil and fitted with a prolongation or tail rod, within which tail rod a stationary tube seated in the hook is adapted to telescope; the oil being thereby forced into and through the stationary tube and thence upon the plunger into the vertical chamber of the hook, where it exerts accumulated pressure. The air that drives the piston during the stroke is utilized to drive it back for another, being finally expelled through the exhaust during the next succeeding stroke. This effects an important saving in the quantity of air used.



FIG. 385.—CASEY PNEUMATIC PUNCH.

The cylinder, cap, and hollow piston are made of aluminum in order to make the machine as light as possible. It is a great saver in time and help in sheet metal, plate, and light structural work.

The smallest size, No. 0, punches $\frac{3}{16}$ -inch metal and under, and weighs but 28 pounds, using $\frac{2}{10}$ cubic foot free air per stroke.

No. 1 punches up to $\frac{3}{8}$ -inch metal, weighs 143 pounds, and uses 1 cubic foot free air per stroke. No. 2 punches $\frac{3}{4}$ -inch metal, weighs 775 pounds, and uses 3 cubic feet free air per stroke. No. 3 is a still larger machine adapted for heavy punching, using 5 cubic feet free air per stroke.

COMPRESSED AIR IN RAILROAD SHOPS.

There seems to be no end to the use of compressed air in railroad-car construction and repair shops. Besides driving motors for drilling, reaming, and wood-boring; hammers for chipping, riveting; motors for running special machines; lifts, jacks, and many other devices described in this work, we may add a pneumatic press for bending eye-bolts, brake-hanger hooks, bar-straps for braces, and truck-frame construction. The horizontal pneumatic press, called the bulldozer, mounted on a strong frame with abutting anvils, with the frame on wheels for portability, is a handy helper for the power to easily accomplish a great variety of work in the car shop. It is a wonderful blacksmith helper in bending, upsetting, and riveting on the parts of locomotive and car work, upon which a large number of processes are necessarily duplicated. The stationary pneumatic hammer in the blacksmith shop is a most useful appliance, and does away with the discomforts of the steam hammer by giving fresh, cool air to the workers. Pneumatic punches and shears are among the useful tools not here illustrated. The portable sand-papering disc and the emery wheel are now driven by a rotary air motor.

The stay-bolt cutter operated by the direct pressure of air is one of the handy tools in the boiler shop. The shearing off of stay bolts is tedious work when done by hand. A balanced stay-bolt cutter or shears operated by direct-air pressure and the double toggle joint and lever, as shown in Fig. 386, has an immense power for cutting and shearing. Thus a cylinder only 10 inches in diameter at 60 pounds air pressure gives a gross

pressure to the toggle and levers of 4,700 pounds; which multiplied by a leverage of 3 is equal to 7 tons; which again increased by the size of the angle of the toggles may be made to apply a pressure of 40 or more tons to the biting jaws, accomplishing work in a few seconds that would otherwise require several minutes. This gain counts in the day's or week's work, and soon pays in every department for a complete equipment in compressed-air appliances.

One of the many useful tools operated by compressed air in the locomotive-boiler shop is the bolt-nipper, of which one type of air-operated nippers has cut off in one case all the stays in the firebox of a Brooks "ten-wheeler" in three hours, and was handled by two boys, a job which formerly occupied a boilermaker and helper nearly two days. This is a saving in cost of about 90 per cent, and the same work with this tool in another erecting shop resulted in a saving of 86 per cent. The nippers cutting off from both sides at once, do not injure the sheet or loosen the thread, as may be done by chipping the stays off.

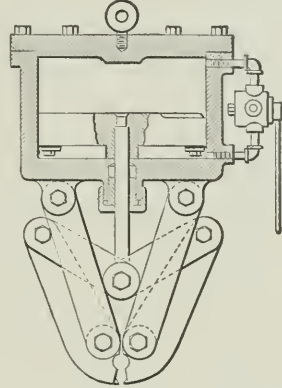


FIG. 386.—STAY-BOLT CUTTERS.

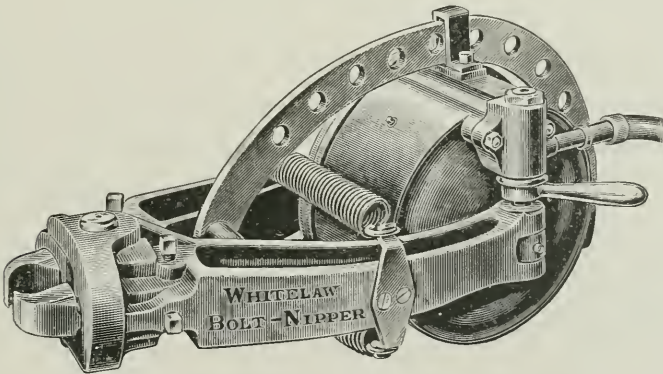


FIG. 387.—THE PNEUMATIC STAY-BOLT BITER.

Two strong pivoted levers operated by an air piston. No. 1 will cut stay bolts up to 1 inch diameter, and No. 2, up to 1½ inch diameter.

Figs. 388 and 389 are a front view and side section of a car-wheel jack, used for loading fitted-up car-wheels upon platform cars for transportation. Fitted to the head of the pneumatic piston is an arm with bearings which engage the axles and lift them to the level of the platform car upon which they are to be

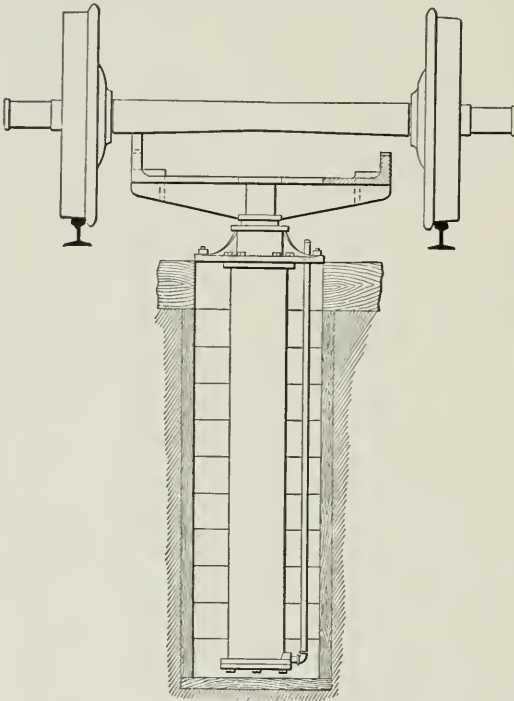


FIG. 388.—PNEUMATIC CAR-WHEEL JACK.

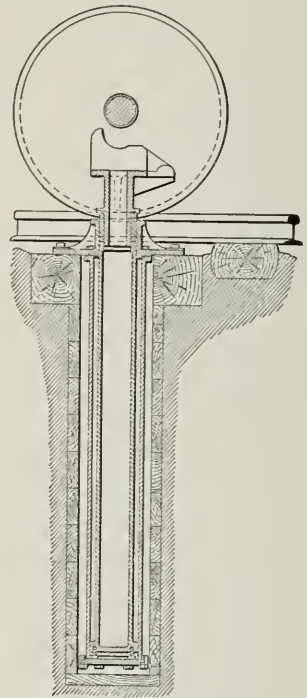


FIG. 389.—SECTION OF CAR-WHEEL JACK.

loaded. By this device the many accidents to laborers loading in the old way by skids are entirely eliminated.

The jack is usually a cast-iron cylinder sunk in a pit between the rails of the track on which the wheels are to be loaded.

Apart from the many pneumatic tools used in railroad shops described and illustrated in other parts of this book, we may mention the pneumo-hydraulic rail-bender and straightener, the pneumatic machine for putting on air-brake hose, a troublesome job to do by hand, and the pneumatic car-lifting

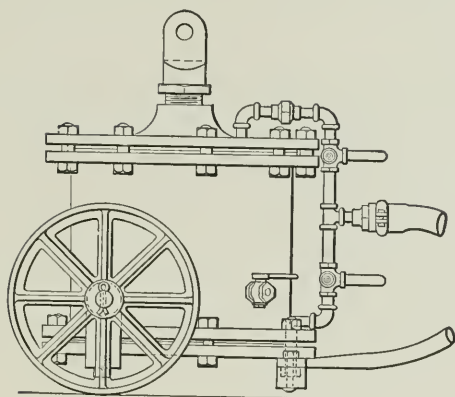


FIG. 390.—PULL-DOWN JACK.

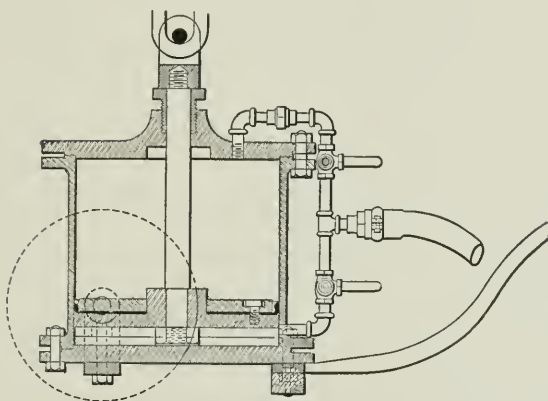


FIG. 391.—SECTION, PULL-DOWN JACK

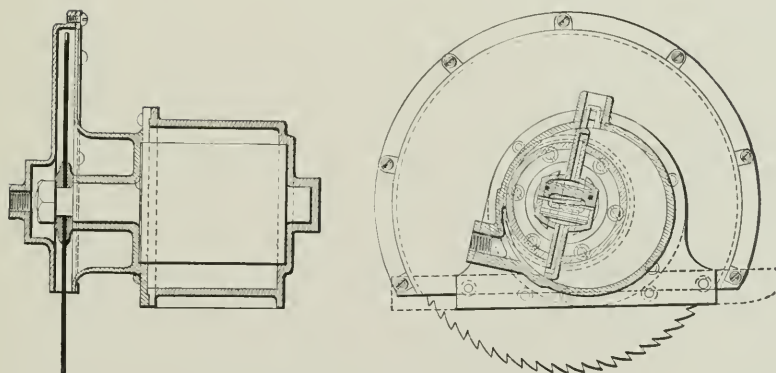


FIG. 392.—SECTION, PNEUMATIC MOTOR SAW.

jacks and presses for putting car-wheels on their axles, and for removing them.

The pull-down jack is similar to the lifting jack, only that it has a double-acting piston, and its special use is in repairing cars, for removing draft timbers and sills. It is illustrated in side view and section in Figs. 390 and 391. It is moved on truck wheels by a thill handle, and can be used also as a lift.

Fig. 392 shows a small, direct-connected motor saw, operated in the hands of workmen. It is used much about the body work on cars, and for cutting off the ends of car roofs.

Chapter XXV.

AIR AS APPLIED TO PYROMETRY

AIR AS APPLIED TO PYROMETRY.

AIR, unlike metals, is a perfect thermometric or pyrometric substance. The action of the air pyrometer is based on a principle which involves the law of the flow of air through small apertures. The development of the instruments has extended over a considerable period of time, and the air pyrometer has been on the market in its present form during the past five years, being now recognized as an absolute standard in the determination of high temperatures.

Its application covers a wide field, comprising principally the measurement and autographic recording of the temperature of the hot blast, the escaping gas of a blast furnace, and the determination of the heat of annealing and tempering furnaces; by a knowledge and record of which steel can be treated accurately and with consistent results. It is essentially a device adapted to practical working conditions, cannot be injured except through mechanical abuse, and will give the same relative readings month after month irrespective of whether it is used constantly or intermittently. This last, together with the fact that it is a recording pyrometer, establishes its chief value in industrial operations, for if the calibration of a pyrometer changes with time, and the readings are relied upon to regulate the temperature, even worse results will be obtained than where no determinations are made. The record renders it possible for the one in charge to know definitely whether or not his instructions are being followed, and furnishes a guide for future operations.

The complete apparatus consists of three parts: the regulator, or main portion of the instrument; the fire tube, or part applied to the heat which is connected with the regulator at

any distance from 10 to 300 feet; and the recording gauge, which is also connected to the regulator, and by means of which

a record of the temperature is printed on a strip of paper.

The regulators are made in two forms, known as single and double. The first permits of the attachment of one fire tube and one recording gauge, and the second of two fire tubes and two recording gauges, so that in the latter case the heat may be measured in two places at the same time.

The fire tubes are made in two forms, blast furnace and portable; the former being used exclusively at blast furnaces, while the latter, as implied by its name, is attached to the regulator by a flexible connection which permits of its use at any point within a radius equal

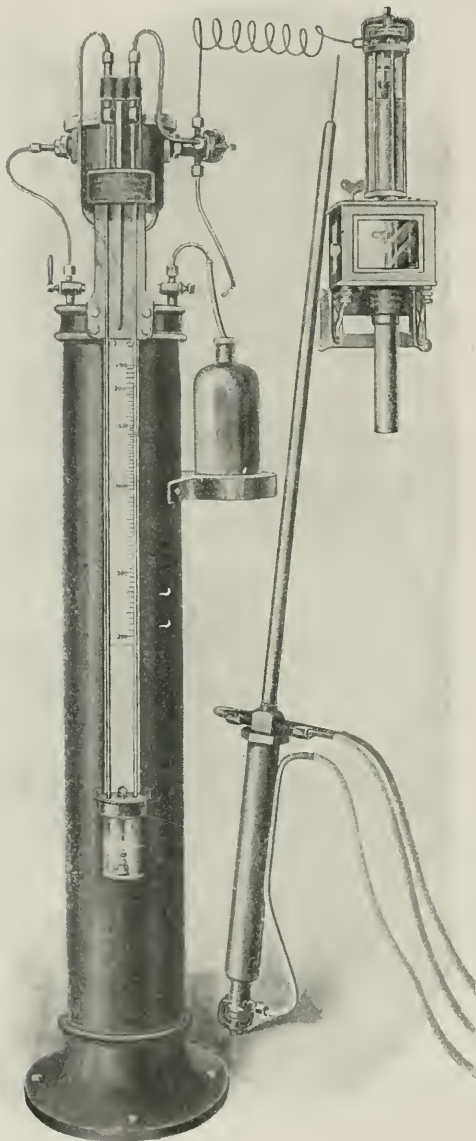


FIG. 393.—THE AIR PYROMETER.

to the length of this connection. This form of fire tube is used on annealing and tempering furnaces and for similar pur-

poses, the regulator and recording gauge being located centrally so that the fire tube can be inserted successively in any one of a number of furnaces or allowed to remain for a greater or less time in any one furnace as desired. The blast-furnace fire tubes can be used with either the single or double regulator, as can also the portable fire tubes.

The recording gauges vary only in their calibration, this being governed by requirements. They can be so adjusted that the limiting lines of the record shall be 200° and $3,000^{\circ}$ F., or any intermediate points may be chosen, such as 500° and $1,500^{\circ}$, $1,000^{\circ}$, and $3,000^{\circ}$. Either the Fahrenheit or Centigrade scale is obtainable.

Fig. 393 shows a single pyrometer. On the left is the regulator, and connected to it on the right is the recording gauge; a portable fire tube rests against the recording gauge. On the front of the regulator is a scale graduated from 100° to $1,400^{\circ}$ C., or from 200° to $3,000^{\circ}$ F. When the instrument is in operation the temperature to which the fire tube is subjected is shown at all times by the water column on front of scale.

Fig. 394 shows the recording gauge. The record is on a continuous strip of paper, and the scale is very open. The records can be removed every day, once a week, or once a month as desired, the back record being always accessible if the charts are detached at long intervals.

As previously stated, the pyrometer is based on the law governing the flow of air through small apertures. Referring to Fig. 395, if two such apertures, *A* and *B* respectively, form the inlet and outlet openings of a chamber, *C*, and a uniform suction is created in the chamber *C'* by the aspirator *D*, the action will be as follows:

Air will be drawn through the aperture *B* into the chamber *C'*, creating suction in chamber *C*, which in turn causes air from the atmosphere to flow in through aperture *A*. The velocity with which the air enters through *A* depends on the suction in the chamber *C*, and the velocity at which it flows out through

B depends upon the excess of suction in C' over that existing in the chamber C , that is, the effective suction in C' . As the suction in C increases, the effective suction must decrease, and hence the velocity at which air flows in through the aperture

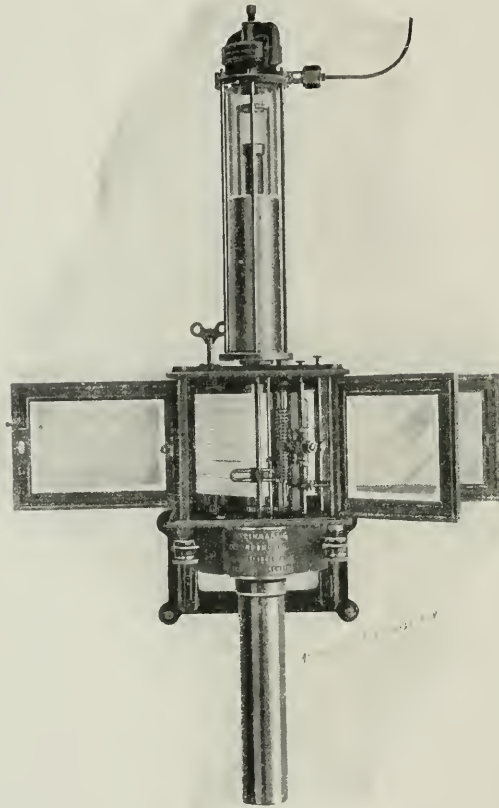


FIG. 394.—THE RECORDER.

A increases, and the velocity at which air flows out through the aperture B decreases, until the same quantity of air enters at A as passes out at B . As soon as this occurs no further change of suction can take place in the chamber C .

Air is very materially expanded by heat. Therefore the higher the temperature of the air the greater the volume, and

the smaller will be the quantity of air drawn through a given aperture by the same suction. Now if the air, as it passes through the aperture *A*, is heated, but again cooled to a lower fixed temperature before it passes through the aperture *B*, less air will enter through the aperture *A* than is drawn out through the aperture *B*. Hence the suction in *C* must increase and the effective suction in *C'* must decrease, and in consequence the velocity of the air through *A* will increase, and the velocity of the air through *B* will decrease, until the same quantity of air again flows through both apertures. Thus every change of temperature in the air entering through the aperture *A* will

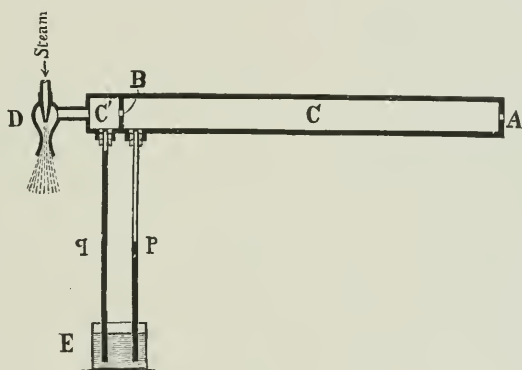


FIG. 395.—THE PRINCIPLE.

cause a corresponding change of suction in the chamber *C*. If two manometer tubes, *p* and *q* (Fig. 395), communicate respectively with the chambers *C* and *C'*, the column in tube *q* will indicate the constant suction in *C'*, and the column in tube *p* will indicate the suction in the chamber *C*, which suction is a true measure of the temperature of the air entering through the aperture *A*.

In its practical application the aperture *A* (Fig. 395) must be so located that the air before passing through it shall acquire the temperature which is to be measured, and this is accomplished by placing it at the end of a small platinum tube *e* (Fig. 396), this being enclosed within a larger tube *d* of the same material, so that the aperture *A* comes within a short distance

of the closed end of the tube *d* which protects it. Both tubes, *d* and *c*, are brazed into drawn copper tubes, *e* and *f*, the length

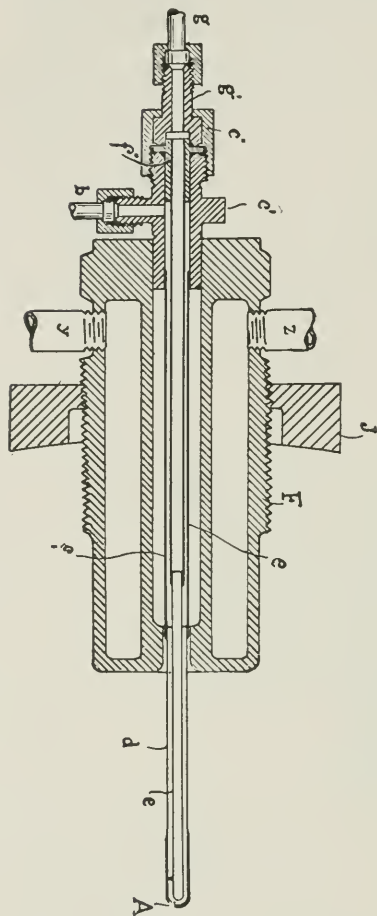


FIG. 396.—PYROMETER TUBE AND PLUG.

of which depends on the length of the water-cooled jacket *F*. The tube *c* is soldered into the coupling piece *c'*. The tube *f* terminates in a flanged head *f'*, and is secured to the coupling piece *c'* by the follower *g'* and nut *c''*. This combination is called the "fire tube."

The fire tube is placed within a water-cooled jacket *F*, which is fed by water entering at *y* and escaping at *z*. This jacket protects those parts of the fire tube that are susceptible to injury by heat. The aperture *A*, being thus disposed, can be readily located so that the air must have attained the temperature of the furnace before passing through.

As shown above, the air passes in at *b* and thence between tubes *d* and *c* through aperture *A* and into tube *e*, being drawn from here to the regulator through an air-tight connection. In order that this air shall be perfectly clean and thus avoid clogging the small aperture *A*, it passes through a cotton filter before going in at *b*. This cleans it thoroughly.

It is also necessary to so locate aperture *B* (Fig. 395) that before passing through it the air shall acquire a fixed temperature, and to provide for this it is placed within a coil and the coil surrounded by steam at atmospheric pressure. This secures a uniform temperature of 212° F., and the method of

arrangement can be seen in Fig. 397, where *B* is the aperture, *G* a pot into which exhaust steam from the aspirator is led, and *t'* the large-volume drain pipe carrying off the steam and condensed water.

The operation of the instrument will be understood by referring to Fig. 398, which is a diagrammatic disposition of the parts. The interior of the pipe, *e*, *f*, *g*, *h*, *i*, from aperture to aperture, together with the branches *q* and *s*, constitute the chamber *C* of Fig. 395. Its inlet from the atmosphere is through the opening *a* at the bottom of the filter *I*, and its connection with chamber *C'* is through the pipe *i*.

The aspirator *D* exhausts into the chamber *G*, keeping it at a constant temperature of 212° . The steam and condensed water escape through the pipe *t* at atmospheric pressure. Opening the valve 6 steam enters the aspirator *D*, and sucks the air through the tube *m*, out of the chamber *C'*, and produces a suction, which is kept constant by the regulator *H* as shown by the manometer *p*. With a constant suction in *C'* and cocks 2 and 4 open, air will enter at *a*, pass through the filter *I*, where it is purified, then through the connection *b* into the fire tube. It

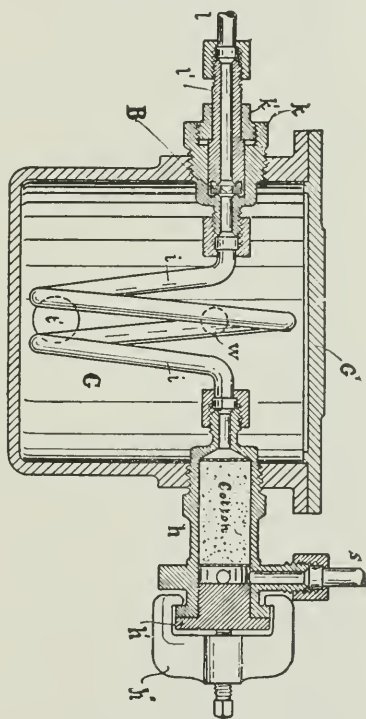


FIG. 397.—STEAM HEATER.

flows forward in the space between the two tubes *c* and *f*; as soon as it reaches the platinum tube *d*, which protrudes from the cooler, it becomes heated and enters through the aperture *A* into the chamber *C*, at the temperature surrounding the exposed end of the fire tube, which is the temperature to be

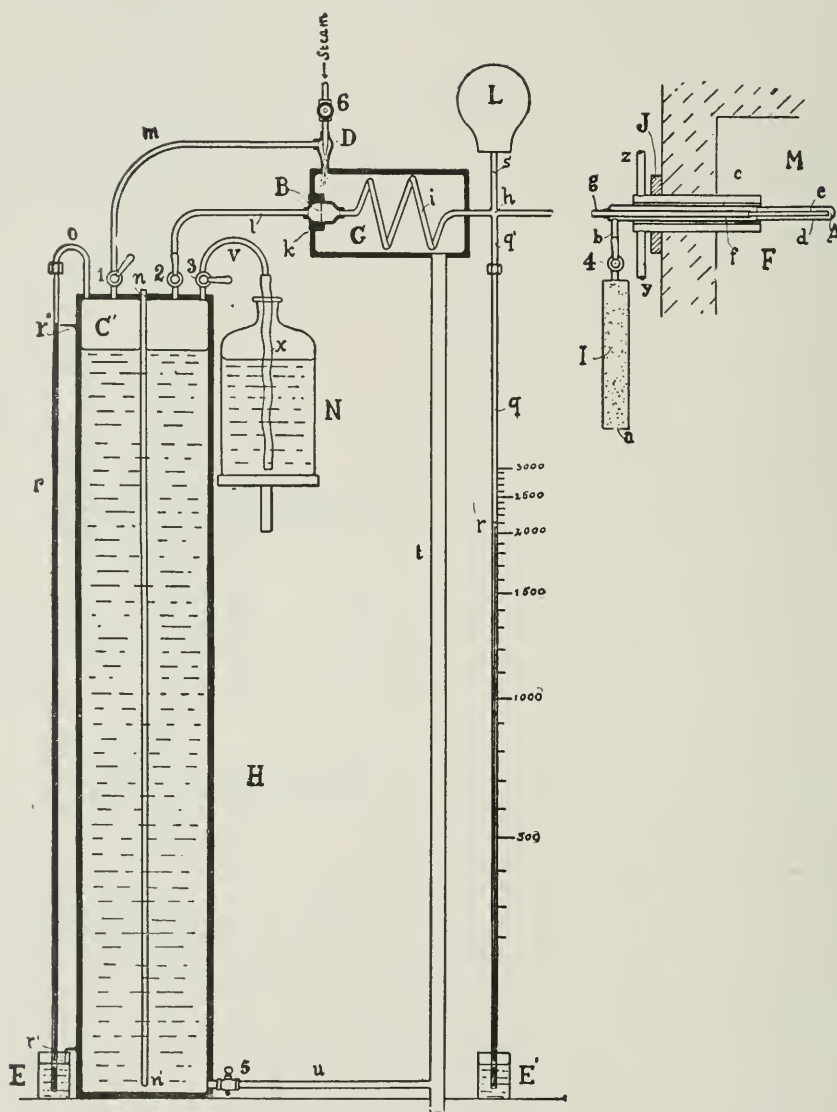


FIG 398.—DETAILS OF THE AIR PYROMETER.

Uehling-Steinbart Company, Carlstadt, N. J.

measured. After passing *A*, the air flows through the pipe *e*, *f*, *g*, *h*, into the coil *i*, where it assumes the temperature of 212° , at which it passes through aperture *B*, thence by the connection *l'* into the chamber *C'*, from which it is drawn by the aspirator *D* through *m*, and discharged with the exhaust steam and condensed water.

The branch pipes *s* and *q'* connect respectively with the recording gauge *L* and the manometer *q*, which is placed in front of the temperature scale on the regulator.

This detailed description of the working principle of the pyrometer may lead to the belief that it is complicated and not readily kept in order. Such is not the case, for it must be remembered that the only moving parts, aside from the recording device, are steam and air. Wear is thus eliminated, and the continuous use of the instruments under the most adverse conditions attests their practical merit.

THE ELECTRIC CURRENT INDICATING METER.

The principle on which the operation of these meters are based consists in causing the variations in the electric current to be measured to control the variation in pressure of a body of air in a closed vessel, this variation being in turn indicated by the rise and fall of a column of non-volatile liquid in a glass tube, back of which is secured the scale.

In Fig. 399, assume that some source, say a small pump, is delivering air at a fairly constant pressure of about $1\frac{3}{4}$ pounds per square inch through the pipe *A*. This enters the chamber *B* and then flows through a series of porous diaphragms made of filter paper whose function is to serve as an air resistance, incidentally serving to remove any dust particles. The air then enters the passage *D* into which is drilled the opening *E* which is capped by the valve *F*.

The valve consists simply of a small flat disc of non-oxidizable metal *F* resting on a circular seat with escape ports *G* below

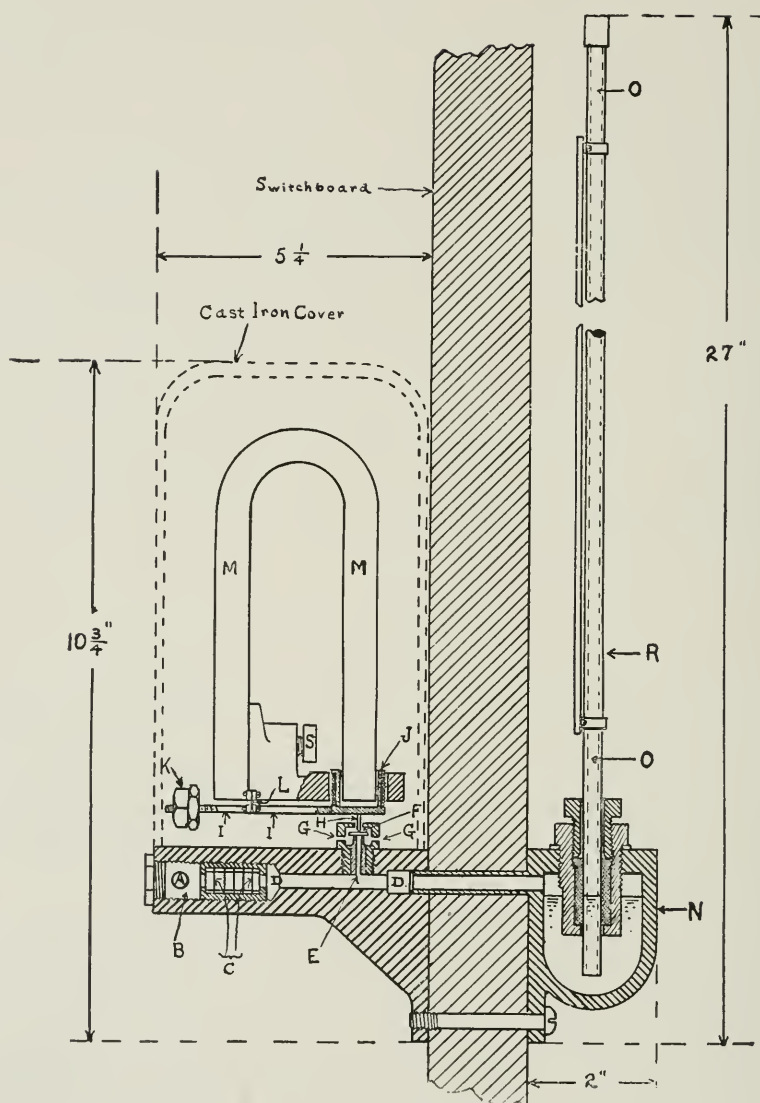


FIG. 399.—COLUMN TYPE, ELECTRIC CURRENT INDICATING METER.

Machado & Roller, New York City.

it and a pin H resting on top. On the pin rests a spool J carried by one end of the lever I , on the other end of which is a counter-weight K , by means of which the effective weight on the pin H can be adjusted.

The spool is wound with wire through which the current to be measured is passed, this being done via the two short thin copper ligaments L which support and form the pivots about which the lever can oscillate.

A magnet M furnishes a field of force such that the reaction between it and the current pinels the spool down with a force increasing as the current increases. The valve F is thus a variably loaded safety-valve whose blowing-off point is constantly and proportionately varied by the current variation. The counter-weight K on the lever is so adjusted that when no current is passing through the spool the weight on the valve pin is such that the blowing-off pressure in D is sufficient to force the liquid in the closed chamber N up through the glass tube O to a height R , which therefore is the zero of the scale. The pressure cannot go above this when no current is on, as any tendency to increase simply results in lifting the valve slightly higher, whereupon more air escapes and the pressure falls back; nor can it go lower, for if there were this tendency the valve would partially close because of the spool weight, and the less rapid escape of air through it would cause the pressure to build up again because of the constant flow of air from the high-pressure supply at A through the air resistance C .

Exactly the same thing holds good when the weight on the valve is that due to the non-counterbalanced portion of the spool weight *plus* the downward thrust caused by a given current through it. This gives what is practically a heavier loaded safety valve, so that the blowing-off pressure in N is higher, and this higher pressure of course forces the liquid up further in the glass tube, thus showing the presence of a current. The height to which the liquid rises is directly a measure of that current, because the extra downward thrust on the spool is,

from the magnetic field and spool design, proportionate to the current.

The air resistance C not only prevents the action from being so sudden that the indications are not dead-beat, but in the case of a decrease in current strength allows the air in the closed

chamber N to flow back promptly and so register the decrease. The glass tube being but 24 inches long, the pressure at A (equivalent to about a 49-inch column of the liquid) is always sufficiently in excess of that in the passage D and the chamber N to cause the changes to be promptly registered.

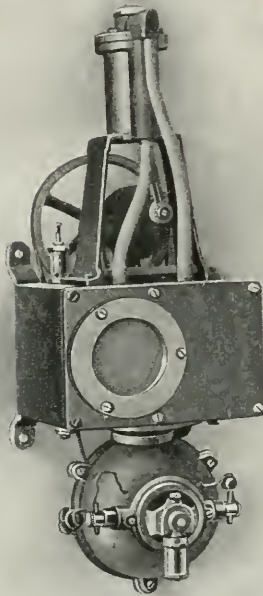


FIG. 400.—ELECTRIC AIR COMPRESSOR.

or down the tube. For actual calibration before shipment an iron screw S of heavy cross-section is provided, which, on being brought closer to or further from the opposite leg of the magnet, weakens or strengthens the field in which the active spool works by shunting a portion of the lines.

It should also be noted that the only work that the varying current has to perform is to *control* the air pressure.

To furnish the air required for the operation of the column type of instruments, this is one of two separate types of devices.

The first is a simple, single-cylinder, single-acting air pump, mounted on a square iron box which serves as an air reservoir, and driven by a one-twentieth horse-power motor suspended underneath and connected to the pump by a belt. This type is of sufficient capacity to run fifty indicators or twelve recorders, the construction of the latter being such that they require nearly four times as much air as the former.

The motor is furnished for either a 110 or a 220 volt circuit, and for either direct or alternating current, as may be desired.

The second type is a water-operated compressor, which operates like an injector, the water carrying the air with it and compressing it to the desired point. These require about ten gallons of water per hour per instrument, with 3-foot head, and are built in sizes to suit the particular installation.

THE COMPRESSED-AIR ELECTRIC RECORDING METER.

This is the same in principle as the indicating type described on the preceding pages. Instead, however, of employing a rising and falling liquid column in a glass tube to give visual indications of the current changes, the column is made of much larger diameter and carries a hollow float supporting a rod with a pen at the extremity thereof, which in turn traces a line on a sheet of paper carried before it by a clock movement.

By making the column diameter of a proper size the pen friction becomes negligible compared to it, and the pen can be made to carry a supply of ink sufficient for long records without having this varying weight destroy the accuracy of the indications.

The illustration (Fig. 401) gives a section of this recorder, similar parts being lettered the same as those in Fig. 399. It will be noted, as above stated, that the only additions comprise the float *P*, the rod *Q*, and the pen *R*, together with the drum *S*, which is rotated one inch an hour by internally placed clock-work, and to the surface of which is secured the record paper.

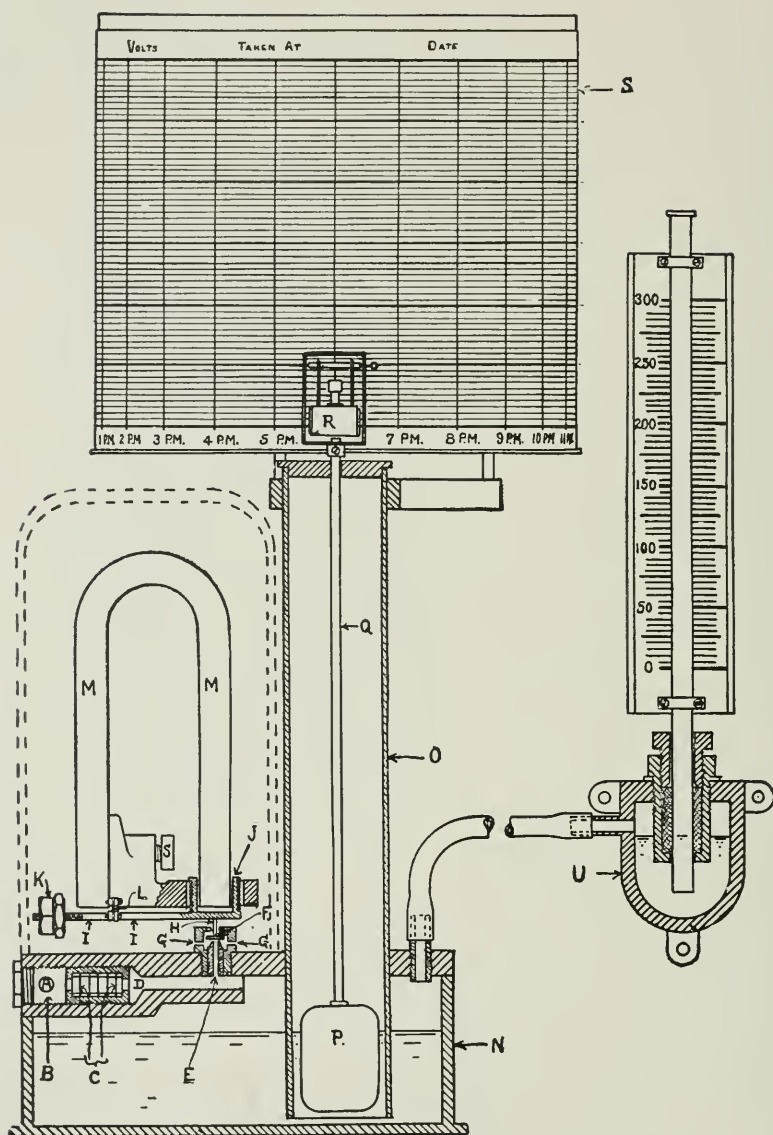


FIG. 401.—SECTION OF THE VOLT AND AMPERE RECORDING AND INDICATING METER.

Particular attention is invited to the fact that, owing to the absolutely dead-beat indications which this class of apparatus gives, the meters never run over; *i.e.*, any fluctuations shown by them are true fluctuations, and their values are not added to by the inertia of the moving parts.

Another unique feature that these devices possess is this: By drilling an additional hole through the cap forming the top of the chamber in which the liquid is contained, and connecting this by a tube with a second closed vessel *U*, similar to *N* in Fig. 399, the liquid in the tube dipping into this vessel will rise and fall with the rise and fall of the pen, as the variation in the pressure of the air therein is the same as that in the recorder chamber. In this way it is possible to put the recorders themselves in the superintendent's office or elsewhere so that they cannot be tampered with, and place the pilot indicator on the switchboard so that the attendant will have before him a constant indication of what the recorder is doing.

The sole manufacturers of the pyrometric and pneumatic volt and ampere meters are the Uehling-Steinbart Company, of Carlstadt, N. J.

Chapter XXVI.

COMPRESSED AIR IN RAILWAY SERVICE

COMPRESSED AIR IN RAILWAY SERVICE.

It is now forty years since compressed air for street-railway propulsion was agitated and began to take on form in plans for putting this system into practical operation. Although high air pressures had then and previously been produced in an experimental way, the high-storage pressures of the present time were then scarcely dreamed of for practical work. The air-propulsion schemes seem to have slumbered until Captain Beaumont started a compressed-air passenger car with rising storage pressures that finally reached 1,000 pounds, at which the conditions of receiver construction for storage seemed to have reached a limit. At this time (1876), Mekarski was advocating and putting into practice, in France, the system of reheating by hot water and using the evaporated water at high temperatures with the air, and on this system mine-hauling locomotives were operated. The first air-motor car was run in Paris in 1876. This was soon followed by the building of compressed-air railways at Nantes, the suburban roads of Vincennes and Nogent near Paris. In 1890 the Berne, Switzerland, city and suburban railways were opened for operation. The storage pressure there used was 470 pounds, while the car-storage pressure was limited to 440 pounds per square inch. An extended investigation of the operating expenses of this road was made at that time, and was found very favorable to the compressed-air system, being 17 cents per car mile.

The conclusions derived from the investigation of the Mekarski system at Berne for urban and suburban tramway traffic consisted in the pleasing appearance of the motor cars, in the absolutely smooth and noiseless motion, and the total

absence of smoke, steam, or heat; that it had fully vindicated this system as preferable to any other system of tramway traction. At Marseilles, France, the compressed-air tramway storage pressure is 1,200 pounds per square inch.

The reheaters of this system are illustrated in the chapter on reheating. The Hardie system was first on trial on the Second Avenue Railroad in 1879 (Fig. 402).

This system was started in Toledo, Ohio, and in Westfield,



FIG. 402.—COMPRESSED-AIR MOTOR PASSENGER CAR, ON SECOND AVENUE, NEW YORK. 1879-80.

Mass., about 1892, but from some constructive difficulties was changed to electric propulsion.

The Judson system was originally instituted in a revolving drum under the track, driven in sections by compressed-air motors with air compressed in a central station and distributed to the motors through an underground pipe system. This failing in expectations, the Judson system was changed to direct motor traction with the air heated by a small furnace containing a coiled pipe near the motor, in which the air was reheated after passing the reducing pressure valve, thus giving the best effect of reheating in the economy of air power.

This system finally gave way to the Hardie improvements on the Mekarski system, and is now in use in Chicago, Ill.,

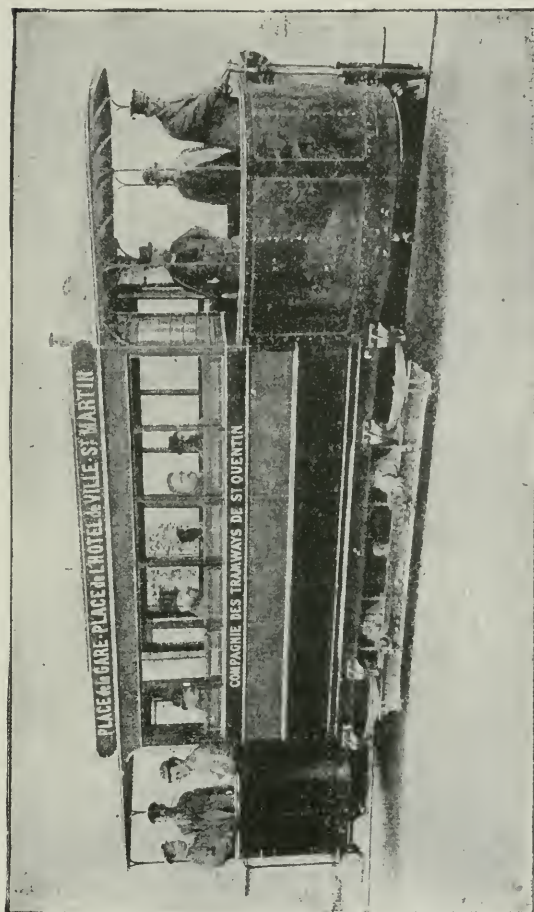


FIG. 403.—COMPRESSED-AIR MOTOR CAR, ST. QUENTIN TRAMWAY CO., FRANCE, MEKARSKI SYSTEM.

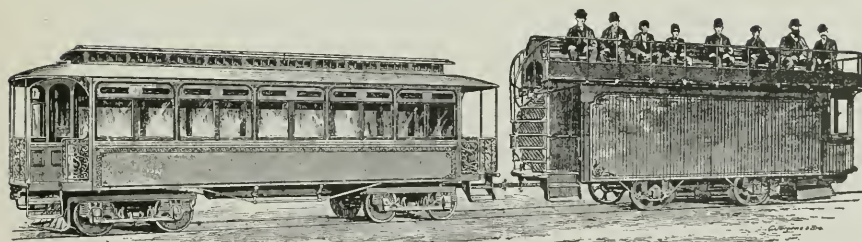


FIG. 404.—THE JUDSON SYSTEM IN CHICAGO, ILL. MOTOR PASSENGER CAR AND TRAILER.

with passenger motor cars, with or without trailers to suit the necessity for traffic accommodation.

In Fig.406 are represented some details of these motor cars, in which the piston in the cylinder *H* is connected by rod with a rock shaft for transferring the line of force to the outside of



FIG. 405.—COMPRESSED AIR MOTOR CAR ON 125TH STREET, NEW YORK CITY.

Storage capacity of car, 51 cubic feet at 2,000 pounds pressure per square inch. Working pressure 150 pounds, reheated by hot water at 300° F., initial temperature. Expansion in cylinders at near atmospheric pressure without noise. These cars have a mileage of from 14 to 20 miles per charge of air, according to condition of track and traffic.

the wheels through the connecting rod *P* pivoted to the parallel-rod connection to the fore and aft wheel cranks. *L* is the brake cylinder, and *F* one of the high-pressure bottles. *M M* are columns in which are placed the controlling gear with their handles at *N*.

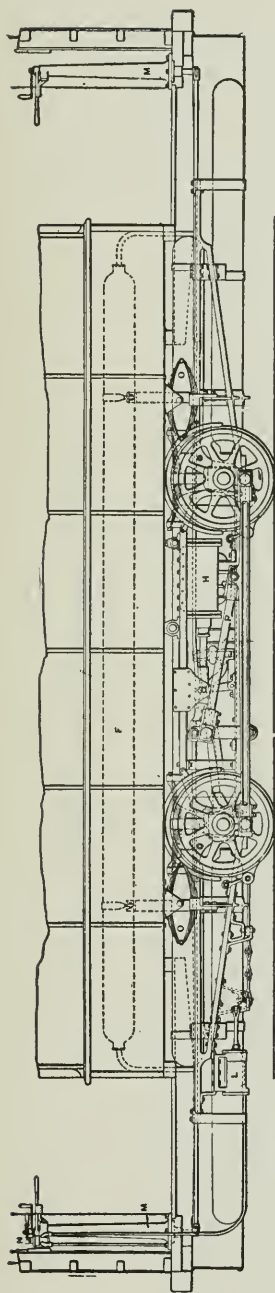


FIG. 406.—AIR CYLINDERS, RUNNING GEAR, AND STORAGE SYSTEM OF THE HARDIE COMPRESSED AIR MOTOR CARS.

In Fig. 407 is illustrated a section of the Hardie motor car of the type used on 125th Street, New York City, showing the location of the high-pressure air tanks *B*, *C*, *D*, *E*, *F*, and the reheating tank *A*; the reducing valve at *G* and the motor cylinder at

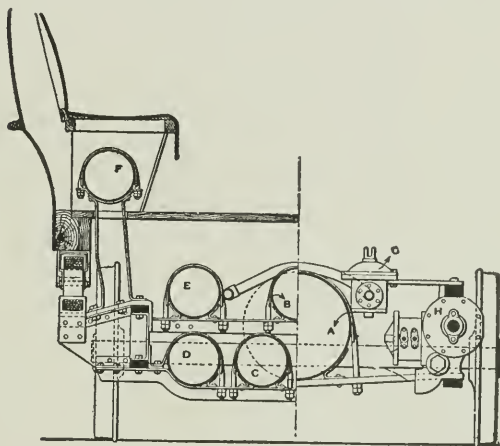


FIG. 407.—SECTION, HARDIE MOTOR CAR.

H. The air passes from the high-pressure tanks to the reducer, then to the reheater, discharging beneath the water and taking on its temperature,

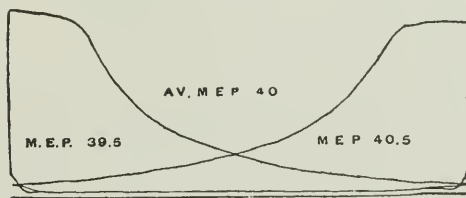


FIG. 408.—THE AIR-PRESSURE CARD.

and is saturated with vapor at a pressure of 150 pounds; then to the controlling valve and expanded in the cylinders to near the atmospheric pressure under normal conditions of running. In Fig. 408 is an indicator card from

these motors showing a mean pressure of about 40 pounds at $\frac{1}{6}$ cut-off.

In Fig. 409 are detailed a plan and elevation of a Hardie motor car, the various parts of which may be measured by the figured scale of the elevation, and in Fig. 405 an outside view of the same style of car now running on the 28th and 29th Streets line of the Metropolitan Railway Company, New York City. Similar cars are running on the street railway system at Rome, N. Y.

The motor cars of the COMPRESSED AIR COMPANY, New York City, are similar, in size and appearance, to standard electric or cable cars, and can be operated at any desired speed. The type of car now in operation weighs about 22,000 pounds. All its machinery and storage apparatus are placed below the body proper. The motor and storage are supported and carried on independent frames and springs which relieve the axle of all pounding and hammering on the track.

The engines of these cars have two cylinders, 7-inch diameter, 14-inch stroke, with driving-wheels of 16-inch diameter. They are equipped with air brakes operated by the same air that runs the motors. The operating levers are placed on the platforms, are simple in form, and of such design that no confusion can arise in the manipulations of the operator.

The storage apparatus consists of sixteen air reservoirs, having a total capacity of 51 cubic feet and weighing 4,340 pounds. One of these is placed under each seat, running the entire length of the car. The others are arranged beneath the floor of the car, and all of them rest on a framework of locomotive construction supported on the usual type of locomotive springs. The framework also supports a heater 7 feet long and 19 inches in diameter that contains 500 pounds of hot water, through which the air passes on its way to the motors.

This type of car has run 17 miles on one charge of air, but is rated as having a capacity of 12 miles, anything over that being reckoned as margin to allow for emergencies, heavy

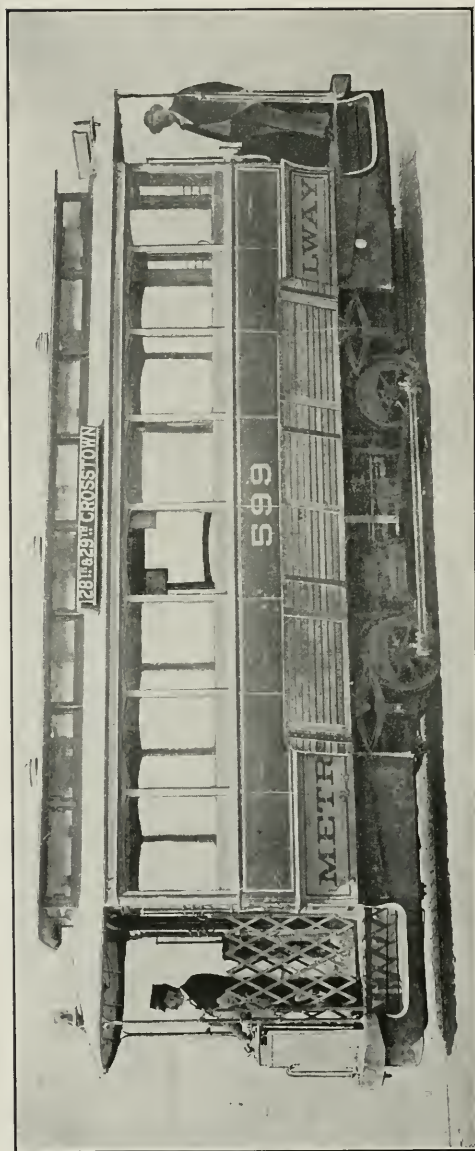


FIG. 410.—COMPRESSED AIR MOTOR CAR OF THE METROPOLITAN STREET RAILWAY CO., 28TH AND 29TH STREETS, NEW YORK CITY. HARDIE MOTOR SYSTEM.

Car 32 feet over all ; seats 30 passengers ; weight of truck and motor, 11,000 pounds ; total weight, 19,000.

loads, frequent stops, bad tracks, etc. Its normal speed is 12 miles an hour, but, like the steam locomotive, it can be operated at any required speed.

In Fig. 411 are detailed the proportions of the reheater used in the cars of the Metropolitan line, 28th and 29th Streets, New York City. It will be seen that the air after pressure reduction to the working limit, 150 pounds, is delivered to the reheater through a perforated pipe lying on the bottom of the cylinder and beneath the hot-water surface. Baffle plates are placed across the cylinder to prevent the water from swashing on starting and stopping the car. A perforated pipe T along the top of the cylinder conveys the air, reheated at the reduced pressure, to the throttle valve on the platform and from thence to the cylinder.

In Fig. 412 is shown the elevation and end view of the motor gear with an outside cylinder connected directly with the crank pin on the wheel. The other wheel is connected by an extension of the wheel crank pins and an outside connecting rod. The rocker arm g is operated by a link l , pivoted to the slide and oscillating on the pivot p , fixed to the frame and also connected by a link to the arm f , which is pivoted to the cut-off valve at m , and to an extension of the wrist pin on the double rocker arm a , which is operated by a sector slide linked to cams on the wheel shaft; so that the main valve and cut-off have variable motion in both forward and backward running.

It is apparent from Fig. 413 that the reducing valve is a diaphragm valve, specially constructed to deal with high pressure, and that, in addition to the ordinary action of such valves, a supplementary action is brought about by reducing the air pressure that is normally kept above the valve head in chamber A . In ordinary action this valve graduates air to 150 pounds. When it is desired quickly to accelerate under heavy load, a movement of the brake-valve handle to a given position discharges the air from chamber A ; this increases the value of the coil spring beneath the diaphragm, opening the reducing

valve in greater measure, and temporarily increases the working pressure to 200 pounds per square inch, while it is desirable to use that pressure in the cylinders.

Fig. 414 illustrates the operation of the air brake of the

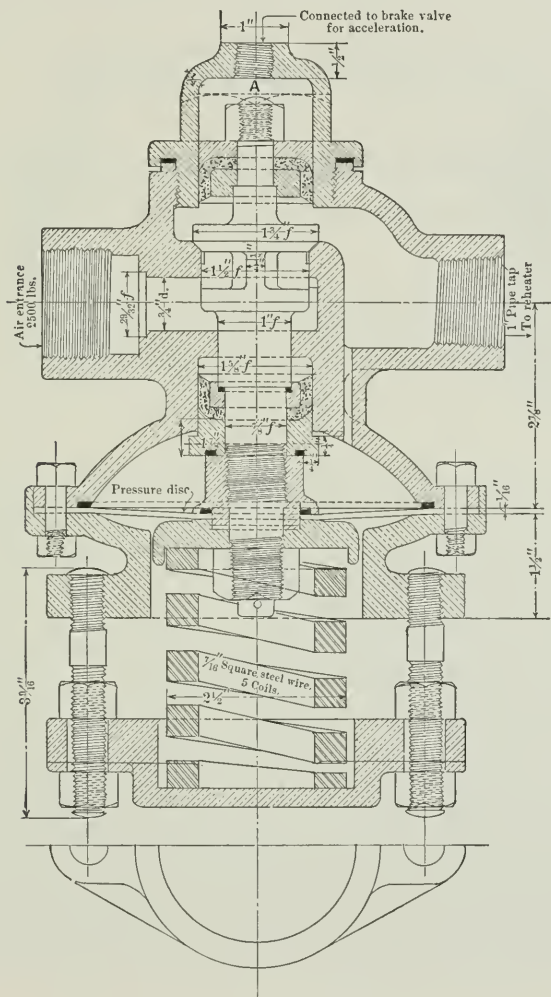


FIG. 413.—DETAIL SECTION OF REDUCING VALVE.

Hardie motor car. The brake piston rod is hollow, and thus forms a cylinder within the brake cylinder.

In the illustration the piston is shown in the set position, and the motorman's brake valve would be in service applica-

tion. Braking force is applied by admitting air to the annular space marked *R*. When release is made the air passes from the point *T* through a by-pass and the release valve to the point *V* in the rear of the piston, and pressure is thus exerted upon the greater area of the total diameter of the piston head. The

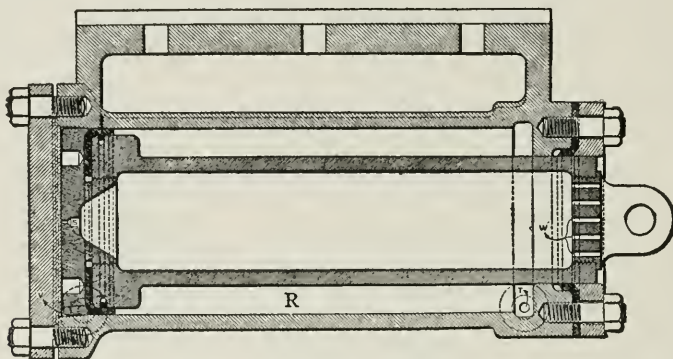


FIG. 414.—THE BRAKE CYLINDER.

difference in pressure area will therefore restore the piston to the release position and the air, thus applied in releasing, bleeds through the opening *S* and out of the hollow piston through numerous ports, *W*, to atmosphere, the bleeding action being so free as to be practically noiseless.

The first compressed-air locomotive for Iona Island, N. Y., to furnish motive power for cars containing ammunition, under contract with the United States Government, has been completed at the H. K. Porter Locomotive Works. It is the type of locomotive decided upon for moving railroad cars about the vast magazines which are the storehouses for ammunition used in the coast defences and forts throughout the country. The engine now finished is a novel one, and was ordered together with a complete plant for charging and operating.

In event of the new locomotive proving a success and standing the tests that it will be put to, the Government will order a number of others like it, all to be used on the same island. Iona Island is probably the greatest storehouse for explosives that is owned by the United States. It is situated in

the Hudson River, a short distance from New York, and from it ordnance and ammunition are sent out to the various points along the coast. For a long time the handling of explosives has been done with mules, dragging cars and carts. It has been a slow and tedious process, as well as a costly one. The island is covered with a series of railroad tracks, and cars from the West Shore Railroad are used in shipping material, being loaded and moved about by teams. It is absolutely necessary that there should be no fire of any kind near the storehouses of the ammunition.

The success that attended the use of compressed-air locomotives in the great plant of the California Powder Company, near San Francisco, drew the attention of the army officials to the availability of compressed-air traction for Iona Island, and after much planning the first plant was ordered. This consists of



FIG. 415.—THE HARDIE COMPRESSED-AIR LOCOMOTIVE.

one locomotive capable of handling standard railroad cars, a series of charging stations along the lines of the rails for charging the locomotives whenever it is necessary, and a complete power plant for operating the compressors.

The new locomotive is said to be one of the largest of its

kind ever built. It will run several miles without being recharged, and can be charged with air at any one of the numerous stations in less than thirty seconds. There being no fire of any kind about the locomotives, there is not the least danger from explosion.

THE COST OF COMPRESSED-AIR RAILWAY SERVICE.

From the few compressed-air railways in which the entire plant has been built for a specific amount of service, accurate returns of cost of operating as compared with the same service of other systems of locomotion have been meagre and unsatisfactory.

The cost of operating the air plant on the Nantes, France, railway has been stated at 12 cents per car mile. It is fifty-eight miles in length and has gradients of four per cent.

The cost of operating the air plant on the Berne, Switzerland, tramway has been given as 17 cents per car mile. The road is two miles or more in extent and has gradients of over five per cent, necessitating heavier power motors than for lower grades.

On the 125th Street line in New York the compressed-air cars were switched in between the cable cars and were limited to their regular speed, not being favored by conditions for clean runs. The frequent stops made necessary by city traffic counted against the best conditions for cost of service, and made the volume of air used larger than for a less obstructed service. The steepest grade on this line is 7.7 per cent, which for only a short run necessitates, as stated for the Berne plant, a heavier motor power than for more even grades. The cars actually operated on this line were two; but the installation was made for a larger number, which brought the operating cost to an excessive figure, viz., 20 cents per car mile. On the basis of a larger number of cars, suitable for the compressed-air installation, the cost has been estimated at less than 17 cents per car mile. With the

improvements of service now being done the cost should fall to about 13 cents per car mile. The average consumption of free air per car mile on the 125th Street line has averaged during seven months' service 477 cubic feet per car mile. The operation of the air cars on the 28th and 29th Streets line has not yet given sufficient data in regard to cost, as the compressing plant largely exceeds the present needs of the car plant.

It has been estimated that the actual cost of compressing air to 2,500 pounds pressure per square inch, and storing for use in a modern air-compressing plant operated with condensing engines, including coal at \$2.75 per ton, water at \$1 per 1,000 cubic feet, oil and waste, the removal of ashes, labor, repairs, and maintenance of power plant, depreciation and interest on cost of entire power-plant including buildings, for compressing plants of the following capacities, based on the consumption of $2\frac{1}{2}$ pounds of coal per hour per horse power for twenty hours per day, will not exceed the following figures:

Cost per 1,000 cubic feet of free air compressed to 2,500 pounds pressure per square inch:

Station capacity.		Cost.	Station capacity.		Cost.
500 cubic feet per minute. . . .		\$0.0675	6,000 cubic feet per minute. . . .		\$0.0359
1,000	"	.0571	7,000	"	.0342
2,000	"	.0469	8,000	"	.0326
3,000	"	.0419	9,000	"	.0312
4,000	"	.0394	10,000	"	.0300
5,000	"	.0375			

Responsible parties will guarantee that the cost will be less than stated, and the writer believes that the cost in highest-grade plants can be reduced fully 25 per cent. from the above figures.

COMPRESSED AIR FOR UNDERGROUND HAULAGE.

The use of compressed air for underground haulage was probably given its first practical application in the St. Gothard tunnel in 1873 and on, until the tunnel was finished. The initial pressure then used was only 210 pounds in the main tank, re-

duced to a working pressure of 60 pounds in the secondary tank. High pressures had not then entered the realm of the practical use of compressed air; but the early pneumatic locomotives did good work. The modern application of compressed air in mine haulage is exemplified in the operation of pneumatic locomotives in the mines of the Susquehanna Coal Company at Glen Lyon, Pa., where there are two compressed-air motors in operation. The air is supplied by a compressor of the three-stage type, having steam cylinders 20 x 24 inches and air cylinders $12\frac{1}{2} \times 9\frac{1}{2}$ and 5 x 24 inches, with water-jackets and intercoolers, compressing the air to 600 pounds per square inch. The air passes through a line of 5-inch special strong pipe 200 feet to the head of the shaft, down the shaft 800 feet, and then along the gangway about 3,400 feet, a total length of 4,300 feet. This pipe line has a capacity of 580 cubic feet and acts as a reservoir for the compressor. It is coupled together with threaded sockets which are counterbored for a lead filling, which is calked. At intervals of about 200 feet, and at all valves and charging stations, flange couplings are used with lead gaskets. The line is perfectly tight, being tested to 1,500 pounds per square inch. Charging stations are placed where required, and consist of a universal metallic coupling which is attached to the check valve of the locomotive air tanks when a fresh supply of air is required. It requires about one and one-half minutes to complete the operation of charging the locomotive, and reduces the pressure in the main pipe line from 600 pounds per square inch to about 570 pounds per square inch. A charge of air weighs about 380 pounds. The locomotive is of the four-wheel type, having cylinders 7 inches diameter by 14-inch stroke; drivers, 24 inches diameter; weight, 18,500 pounds; length over all, 17 feet 6 inches; width, 5 feet 2 inches; height, 5 feet. The air for propelling the locomotive is stored in two cylindrical steel tanks with a combined capacity of 130 cubic feet and supported by cast-iron saddles resting on the frames of the locomotive. The air flows from the main tanks through a

specially designed reducing valve into an auxiliary reservoir, and from thence through a throttle valve to the cylinders. The pressure in the auxiliary reservoir can be regulated anywhere from 30 pounds up to 140 pounds or 150 pounds per square inch as required. The air in the auxiliary reservoir is maintained at a constant pressure, while in the main storage tanks it may vary from 570 pounds per square inch down to the pressure at which the reducing valve is adjusted; when this pressure is reached in the main storage tanks the air passes through to the cylinders without further reduction in pressure.

The locomotive hauls sixteen empty cars a distance of 3,700 feet into the gangway and returns to the shaft sixteen loaded cars with one charge of air, starting with a pressure of 575 pounds per square inch and ending with about 100 pounds per square inch. The train of empty cars, including the locomotive, weighs 60,000 pounds, and the train of loaded cars, including the locomotive, weighs 166,000 pounds. The grades favor the loads. The locomotive runs from twenty-five to fifty miles per day, depending upon the length of trip and time consumed in making up the trains at the terminals. This locomotive was lowered down the mine shaft a vertical distance of 800 feet without dismantling in any manner.

PNEUMATIC MINE LOCOMOTIVES OF THE BALDWIN LOCOMOTIVE WORKS.

The new modification of the pneumatic locomotives of this company is shown in Figs. 416 to 419, an advance in air-motor design in the ribbed compound cylinders.

Pneumatic locomotives for mine haulage have been in use for several years, and are to-day a standard product of all the large steam locomotive builders. They possess several features which make them ideal for mining purposes and most suitable for quite a variety of surface work, generally industrial operations, such as plantations, tunnels, powder mills, lumber yards,

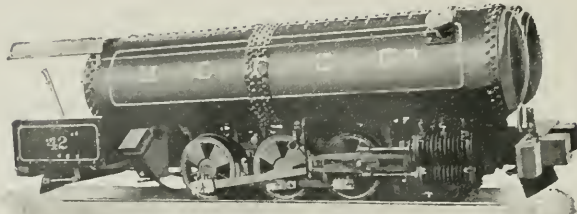


FIG. 416.—COMPOUND PNEUMATIC LOCOMOTIVE.

Six-wheel type. Compound cylinders, ribbed for the absorption of heat from the outer air, thus preventing extreme cold in the exhaust. Built for the H. C. Frick Coal Company.

textile manufactories, cotton mills, storage warehouses, and other places where the risk of fire resulting from sparks and the freedom from other objectionable features make the com-



FIG. 417.—COMPOUND PNEUMATIC LOCOMOTIVE.

Four-wheel type. Ribbed cylinders. Built for the Philadelphia and Reading Coal and Iron Company.

pressed-air locomotive a most desirable and satisfactory means of hauling.

Compressed-air power has marked advantages over any other kind of haulage power for mines and constructive works, where

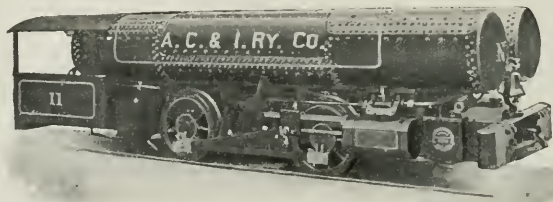


FIG. 418.—PNEUMATIC MINE LOCOMOTIVE.

Two-cylinder, four-wheel type.

the entanglements of electric wires and stays are always in the way, and steam is a nuisance. Compressed-air power is a free traveller to go wherever a track is laid and even without tracks



FIG. 419.—SINGLE-TANK PNEUMATIC LOCOMOTIVE.
Baldwin Locomotive Works.

in the compressed-air driven truck. The distance run with one charge of air is only limited by the capacity of the storage tanks, and since high initial pressure has become available, the limit of usefulness has been largely extended.

COMPRESSED-AIR LOCOMOTIVES FOR HAULAGE.

The mule, which has so long been used for hauling in mines and in yard work, has nearly lost his calling by the successful adoption of the more powerful agent, compressed air, in the

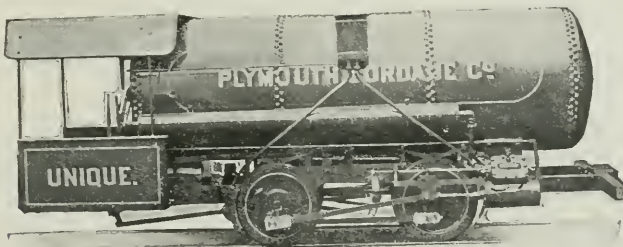


FIG. 420.—PNEUMATIC LOCOMOTIVE FOR YARD AND FACTORY SERVICE.

diminutive narrow-gauge locomotive that needs no feed when no work is being done. The compressed-air system has entirely supplanted steam in underground work, and has become

a most economical competitor of both steam and electricity in yard and factory haulage.

Fig. 421 represents a type of yard locomotive of the H. K. Porter Company, Pittsburg, Pa., designed for factory and yard work. It is built for narrow gauge and with wheel base as short as 3 feet 6 inches, and for curves of 12 feet radius. The single air tank carries a maximum pressure of 600 pounds per square inch, with an auxiliary reservoir from which the motors are operated at not more than 140 pounds pressure. This style of compressed-air locomotive is made in twelve

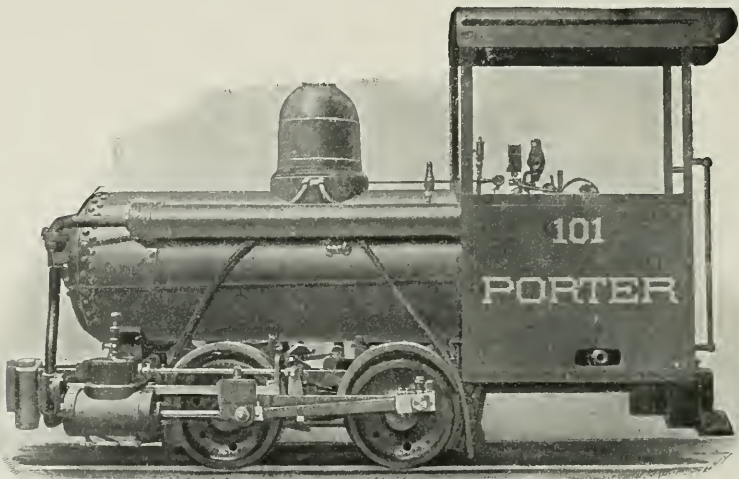


FIG. 421.—INDUSTRIAL PNEUMATIC LOCOMOTIVE.

sizes, the smallest having motor cylinders 4 x 8 inches; the largest, 11 x 14 inches.

The larger locomotives built for the longer runs required on plantations and for shipping heavy goods from iron works and factories are also made in twelve sizes with air-storage capacity of from 45 to 260 cubic feet of compressed air at from 600 to 700 pounds pressure.

COMPRESSED AIR IN RAILWAY SIGNALLING.

Automatic apparatus operated by compressed air for ringing bells at highway crossings are in practical operation. In Fig. 422 is shown an elevation and plan of the apparatus of the Lyman Pneumatic Signal Company of New York.

A small air-compressing cylinder is located near the rail and operated by a lever which is depressed by the wheels of a passing train, sending an air impulse through an underground pipe to a distant crossing which makes an electric contact that rings a bell. *A* is the lever, *S* a slotted cam on a rocking shaft *B*. A train coming in one direction swings the lever and cam shaft and lifts the plate *C* and the connected air piston. A train from the opposite direction only depresses the lever in the cam slot and does not give the air impulse to the signal bell.

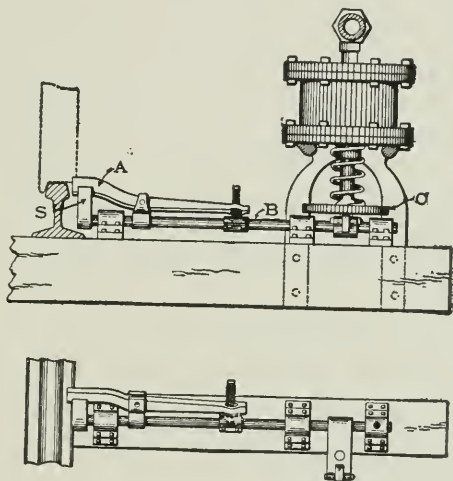


FIG. 422.—SIGNAL AIR COMPRESSOR.

The shortest train repeats the air impulses and furnishes sufficient power to close the bell circuit for the required time for signalling. Fig. 423 shows the method of arranging the position of the air apparatus to the north or south of a crossing.

The central compressor *C* is to open the bell circuit and stops the ringing by making an air impulse on the piston *C* (Fig. 424). Its location should be at the track opposite the signal bell. In operation an impulse of air coming through *n* (Fig. 424) lifts the piston in *N* and, by means of rod 3, closes the electric circuit which rings the bell. The bell rings as long as the

piston of *N* remains up, and this time is governed not only by the length of the train that sends the air impulse, but also by the fit of the piston and the size of the air escape, which can be adjusted for any desired length of time. When the piston in *C* (Fig. 423) is lifted it forces air into the upper ends of *N* and *S* (Fig. 424) and at the same time lifts pins 1 and 2, by which valves *a* and *b* are opened, exhausting the pressure in the lower

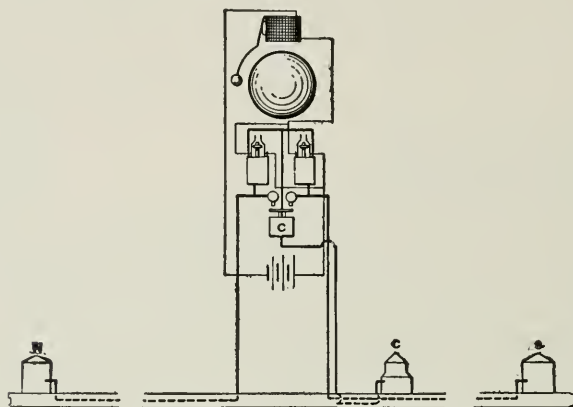


FIG. 423.—THE SIGNAL STATION.

ends of the upper cylinders. The reference letters *N*, *C*, and *S* in (Fig. 424) have the same general meaning as the same letters in Fig. 423.

A pneumatic railway switch and signal system has been devised and put in experimental operation, by which the switches and signals are operated from a distant station by means of compressed air generated by hand power in the switch station in sufficient quantity to operate the local switch and signal plant. The system is operated by a double pipe line with slide-valve connections operated by levers in the signal tower, which by air pressure of about 80 pounds operate pistons in cylinders at the switches and signal poles, and thus throw a switch or signal to its proper position. The system is very complex in its details, which prevents an intelligent illustration here. It is in use on the New Jersey Central and other railways.

THE INTERLOCKING SIGNAL AND SWITCH SYSTEM.

After eighteen years of costly and extensive experimenting, the pneumatic interlocking signal and switch system has been made a success and a fixture at the leading terminal stations in this country. By its aid one man now does the work that would otherwise require the combined efforts of six operators, and he does the work better, the chances for his making mistakes having been reduced to a minimum. With the lever in hand he controls the marvellously efficient interlocking machine, which in turn controls a number of switches and signals connected by pneumatic cylinders. As many as a dozen trains may be rushing down on the signal-house; one movement of his hand—and he has signalled them all; another movement—and he has steered each individual train across a switch, launching it on its proper course. The system in use at the Boston Southern station is the largest known. There are no less than two hundred and thirty-eight pneumatic switches in operation; eleven trains may move simultaneously into or out of the train-shed; one hundred and forty-eight semaphore signals are provided for the four hundred possible routes presented in the switch system of that terminal.

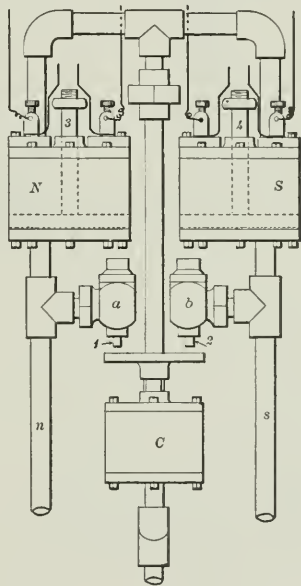


FIG. 424.—AIR PISTONS UNDER THE SIGNAL BELL.

THE PNEUMATIC BAGGAGE-HANDLER.

The Grand Rapids & Indiana Railroad has gone one step farther by lately adopting the pneumatic "baggage-handler" system. This device has proved itself able to handle heavy

baggage much more rapidly than it could otherwise be handled, and, moreover, to do away with breakage. The day of the baggage-smasher may, therefore, be past. The machine is a very simple arrangement of air cylinder and baggage support. The latter is lowered to the platform, where it receives the baggage. Then it rises quickly and is automatically swung around by a cam action, carrying the baggage into the car. The lift is operated by air drawn from the train tanks to a special reservoir, and it is controlled by the baggageman through suitable cocks on the inside of the car. The machine has a lifting capacity of 500 pounds, with 70 pounds of air pressure; it has a spring-

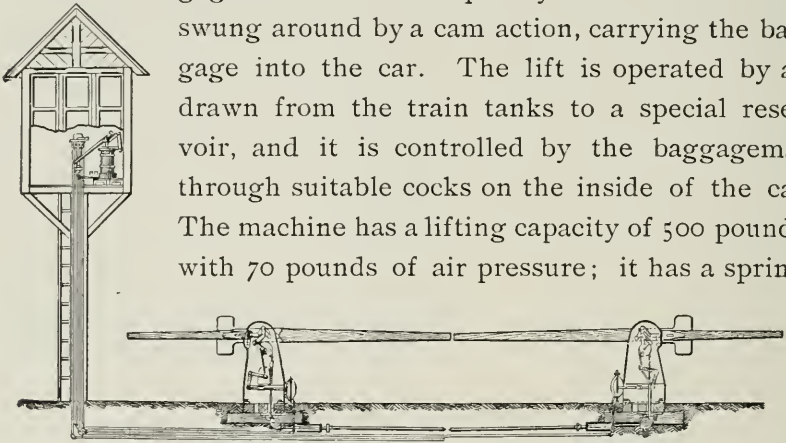


FIG. 425.—THE PNEUMATIC RAILWAY GATE.

scale device providing for the weighing of the baggage as it is handled, and it is able to load trunks at the rate of six pieces every thirty-two seconds. For country stations where now there is only one man to handle the baggage, with the usual disastrous results, this device will save many a trunk from being damaged or smashed.

THE PNEUMATIC RAILWAY GATE.

Among the many applications of compressed air for operating special appliances on railway lines is the pneumatic railway gate. By this appliance the man in the signal-tower with a small hand air-compressor pumps up a pressure sufficient for operating the gates, to which the air is transmitted for a considerable distance by a double-pipe connection with each gate to supply compressed air to each side of a piston, to the rod of which is attached a chain running over a sheave and up over

a sector to which the gate bars are attached. A diaphragm piston takes air by a second pipe line to lock the gate at open and closed position. The gate is balanced so that the effort of opening and closing the gates is very small, and a number of gates may be operated at the same time. About forty railways in the United States are now operating this system. They are built by the Boque & Mills Manufacturing Company, Chicago, Ill.

THE PNEUMATIC DUMPING-CAR.

One of the later improvements in railway-car construction is the compressed-air dumping-car, made by the Thatcher Car and Construction Company, New York City. The body of the car being pivoted centrally will dump to either side, or to one side only, according to its construction. This is done by means of a cylinder mounted on the truck frame, the piston of which is coupled direct to the car body; another small cylinder called the "latch cylinder," fitted with piston rod and slide valve, positively and automatically operates the latches which lock the car body in its horizontal position, and also regulates the air pressure to the large or dumping cylinder as required, moving its piston up and down, thus dumping the load and returning the body to its horizontal position and locking it. An independent reservoir which each car carries contains an ample supply of air for operating the dumping cylinder, and is charged by the engineer through a train pipe used for the air brakes at times when the air brake is not in use. The pressure is held in the receiver by a check valve, so that the action of the air brakes is not interfered with.

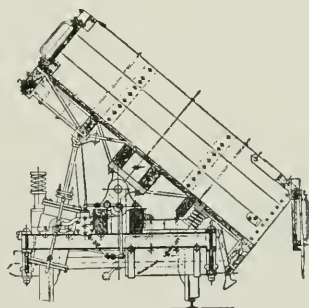


FIG. 426.—THE PNEUMATIC DUMPING-CAR.

THE PNEUMATIC TELEGRAPH.

For local purposes and short distances, so as to connect different parts of buildings, factories, etc., the pneumatic or air-pressure telegraph has of late been successfully introduced. The pneumatic telegraph is operated by compressing a quantity of air in a rubber receptacle and forcing the same through the connecting pipes to act on a second distant receptacle that is held compressed when in a state of rest. The expansion of this second receptacle actuates a bell or other signalling apparatus. The apparatus is, however, not applicable to greater distances, as the volume of air in the communicating pipes is too large to be compressed with considerable power by the pressure exerted by the first receptacle, especially as such pipe connections cannot be kept tight enough to prevent the escape of air. The Italian engineer Guattari has overcome in a simple and ingenious manner some of the difficulties of these telegraphs, by substituting, in place of a few powerful compressions, a quick succession of alternating compressions and dilatations, which produce, so to say, an oscillating motion of the air in the pipes.

THE AIR BRAKE AND ITS WORK.

The air brake dates its practical inception from the year 1869, in the "straight air brake" system of George Westinghouse, Jr.

This consisted of a pump operated by steam from the locomotive boiler, which compressed air into a reservoir conveniently located about the engine. This was under the control of the engineer by means of a valve in a pipe leading from the reservoir. From this valve a pipe extended under the tender and was attached by flexible hose connections to a similar pipe under the entire length of each car. Branch pipes led to "brake cylinders," and the rods of the pistons in the latter were connected with the brake levers on the cars. By placing the brake-valve handle in such a position that the reservoir on the engine was

connected with the train line under the cars, air pressure passed to these cylinders, pushing the pistons outward, operating the brake-levers, and forcing the brake-shoes against the wheels. It was found that the operation of this apparatus was too slow, dangerous when used on long trains, and did not meet requirements.

About 1872 or 1873 Westinghouse produced a "plain automatic brake" which embodied the addition of an auxiliary reservoir and a triple valve to each vehicle. Each reservoir was of a capacity sufficient to provide an amount of compressed air to supply the power for the car on which it was placed.

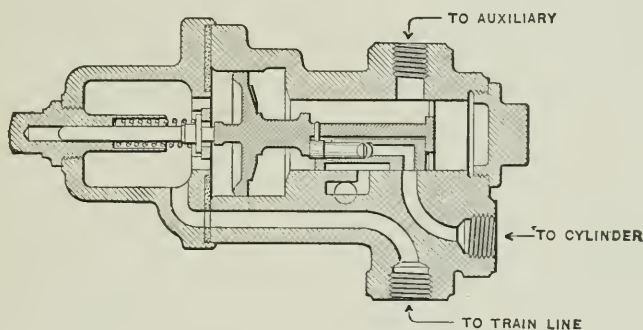


FIG. 427.—PLAIN TRIPLE VALVE.

Showing service position.

The operation of this brake was radically different from that of the "straight air brake." In the former the compressed air was stored in the main reservoir until required for the application of brakes; in the latter the main and auxiliary reservoirs and train pipe were always charged with compressed air at working pressure, to prevent the application of the brakes. The former system was operated by pressure from the main reservoir; the latter system was operated by a reduction of pressure in the train pipe, which reduction caused the triple valve automatically to assume a position that would permit the pressure stored in the car reservoir to flow through the triple valve into the brake cylinder. It was automatic in action in case of accident, such as the bursting of hose or the train breaking in two, but like the

"straight air brake" was not found to be capable of successful operation on long trains of freight cars.

In 1885 the Railway Master Car-Builders' Association arranged for a series of experiments. Several companies entered into the competition, but none succeeded in stopping long trains of freight cars without violent and disastrous shocks. The trials were renewed in 1887, with five competing companies. The report of the committee was against all the competing devices, the committee concluding that air brakes actuated by electricity were the only ones likely to be capable of successful operation on long trains of freight cars.

After these trials Mr. Westinghouse set himself to work to obviate the difficulties that had not yet been overcome, namely, to provide for practically instantaneous application of the brakes throughout a train, and to prevent shocks to the cars.

In the latter part of 1887 he succeeded in constructing a quick-action automatic brake, capable of being successfully applied to a train of fifty or more cars, and operative under all conditions of practical railway service. The requirements with which he then for the first time successfully complied were: 1. The regulation of the force to be applied to the brake-shoes so as to secure all necessary graduations, from the mere slackening of speed to the service-stop, and from the service-stop to the emergency-stop. 2. The automatic operation of the brakes in case of accident. 3. The practically simultaneous operation of the brakes on each car, so that, in long trains of freight cars, shocks might be avoided. 4. The control of all these operations by the engineer. 5. Certainty of operation under all conditions. This was found to be the first system which practically solved the problem of quickly stopping a long freight train in time of danger, and, if desired, also permitted of a gradual application.

Plate A illustrates the relation and general management of the parts of the air-brake equipment on an engine, tender, and passenger car. The tender equipment shows the "plain triple"

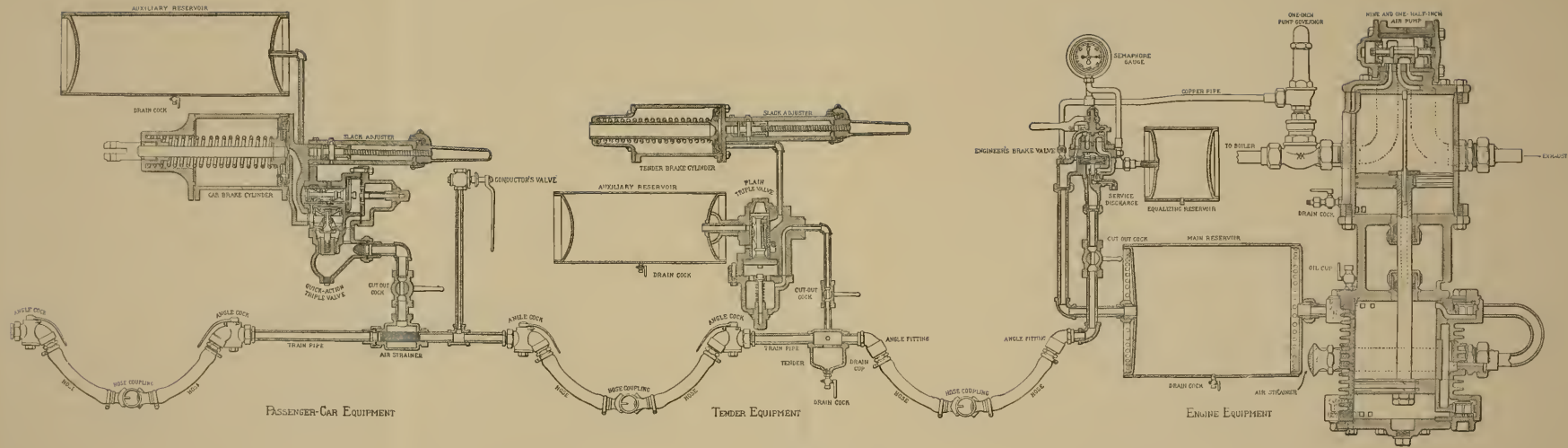


PLATE A.—THE WESTINGHOUSE AIR-BRAKE EQUIPMENT.

valve used on engines and tenders, while the triple valve shown on the car equipment is the "quick-action" type. The main reservoir is carried beneath the engine and is charged with air from a pump also on the engine, the pump being operated by steam from the boiler. The "engineer's brake and equalizing discharge valve" is located in the cab of the engine and is connected to a pipe leading from the main reservoir and a second pipe communicating with the train pipe. This valve, under the control of the engineer, regulates the flow of air from the main

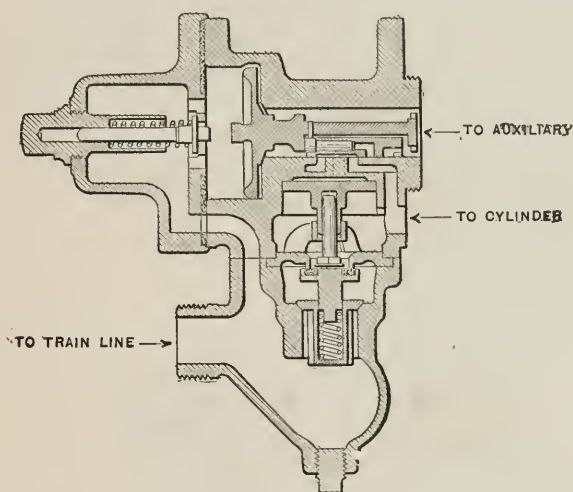


FIG. 428.—QUICK-ACTION TRIPLE VALVE.
Showing release position.

reservoir into the train pipe for releasing the brakes, and charging the auxiliary reservoirs, and from the train or brake pipe to the atmosphere for applying the brakes. The train pipe leads beneath all the cars of a train, being connected between the cars by flexible hose coupled to the pipe sections. By means of an angle-cock at each end of the pipe of each car, such pipe is closed before separating the couplings, thus preventing the escape of air and the application of the brakes when the cars are uncoupled.

Beneath each car is an auxiliary reservoir which takes a supply of air from the main reservoir, through the train pipe,

and stores it for use on its own car. The brake cylinder, by a suitable pipe, is connected to the triple valve, and its piston rod is attached to the brake levers in such a manner that, when the piston is forced out by the air pressure, the brakes are applied. The "quick-action" automatic triple valve is connected to the

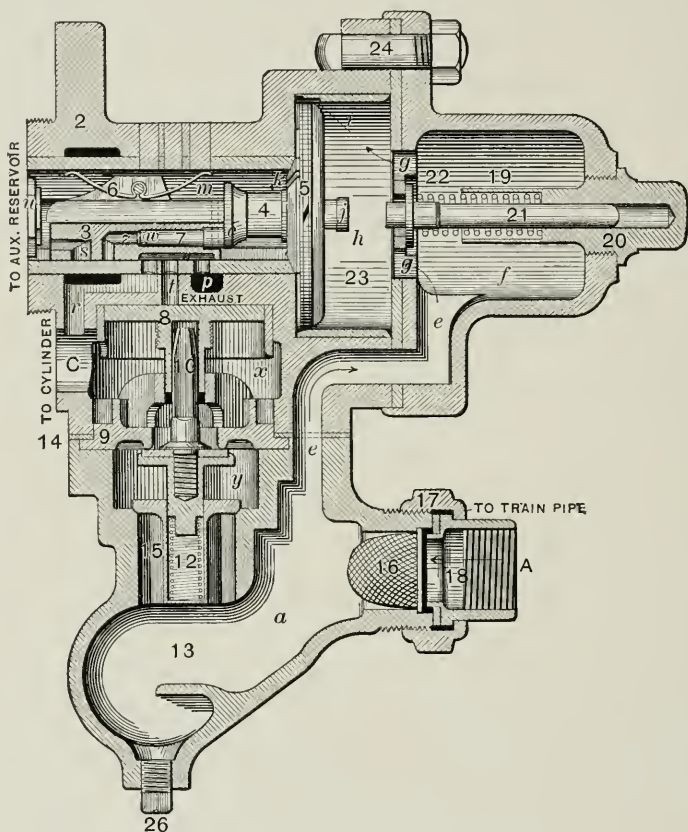


FIG. 429.—QUICK-ACTION TRIPLE VALVE.

Showing release position.

main train pipe, auxiliary reservoir, and brake cylinder, and as its name implies, it, in response to variations of train-pipe pressure, performs three functions in the operation of the brake: applies the brake, releases it, and charges the auxiliary reservoir. When a reduction of air pressure is made in the train pipe, the auxiliary reservoir pressure, which is then

greater, forces the triple piston, and it in turn moves the slide valve, to a position such that a port connection is made permitting air to flow from the auxiliary reservoir to the brake cylinder. If when the brake is applied the engineer permits pressure from the main reservoir on the engine to enter the train pipe, its pressure is raised to an amount in excess of that in the auxiliary reservoir. With the train-pipe pressure greater than that in the auxiliary reservoir, the triple piston and slide valve are forced back to what is known as release position, in which position a port in the slide valve permits brake-cylinder pressure to escape to the atmosphere, and a small port, known as the feed port, connects the two sides of the triple piston, thus recharging the auxiliary reservoir from the train pipe in anticipation of a future use of the brake.

The quick-action triple differs from the plain triple Fig. 427 in that it has supplemental valves which, in case of a sudden reduction, made by the engineer, by the train parting, or otherwise, the brakes are not only applied more quickly, but are applied with greater force due to the supplemental valves unseating, thus allowing a portion of the train-pipe pressure to reach the brake cylinder. The air taken from the train pipe on the first car by the supplemental valves, in an emergency application, causes a sudden reduction which throws the next triple into quick action, this one the next, and so on throughout the train, the brakes applying with such rapidity that, with a fifty-car train, the fiftieth brake will start to apply inside of two and one-half seconds.

PARTS IN THE FOLDING PLATE, A.

AUXILIARY RESERVOIR.—A reservoir, one of which is located under each vehicle, in which air is stored for the purpose of furnishing braking power for the vehicle upon which it is located.

BRAKE CYLINDER.—That part of the brake system in which the piston, actuated by compressed air when the brake is ap-

plied, is located. The piston, acting upon a system of levers, draws the brake shoes against the wheels, thus producing the retarding power which tends to stop the rotation of the wheels.

TRIPLE VALVE.—A valve, one of which is located upon each vehicle equipped with an air brake. It derives its name from the three functions it automatically performs in response to variations of train pipe and auxiliary reservoir pressures; it automatically charges the auxiliary reservoir, applies, and releases the brake.

STOP-COCK.—A valve by means of which the brake on any vehicle may be cut in or out. With each equipment, it is found in the pipe which connects the main train pipe with the triple valve.

CAR DRAIN CUP.—A cast-iron cup in which is placed a piece of perforated brass; it acts as a strainer to prohibit the passage of any foreign substance from the main train pipe into the triple valve.

ANGLE COCK.—A valve, one of which is located at either end of every vehicle. The handle may be turned so that the valve will permit air to pass through into the train pipe beyond, or so as to stop the flow of air by the point at which it is located.

HOSE.—A flexible connection which, with the cast-iron coupling, furnishes a means of connecting the train pipe on one vehicle with that on the adjoining one. In case the train pulls apart the couplings separate, thus permitting of a discharge of air from the train pipe which causes the brakes to apply.

CONDUCTOR'S VALVE.—A valve having a pipe connection to the main train pipe, and so located in baggage, mail, and passenger cars that it is easily accessible to the occupants; by turning the handle of the valve a sudden discharge of air is made from the train pipe, thus causing a rapid application of the brakes throughout the train.

ENGINEER'S BRAKE VALVE.—A valve, located within convenient reach of the engineer, by means of which he is enabled to control the amount of train-pipe pressure carried, the ap-

plication and release of the brakes, also the recharging of the brake system.

BRAKE-VALVE RESERVOIR.—Usually located beneath the cab foot-boards, it furnishes a considerable volume of air above the equalizing piston of the brake valve; this volume permits the engineer to make a gradual reduction of pressure above the piston, in response to which it rises gradually, thus allowing train-pipe pressure to escape at the “train line exhaust,” comparatively slowly. A slow reduction causes a gradual application of the brakes, as in station stops; a quick reduction causes a quick application of the brakes, such as is used in cases of imminent danger.

PUMP GOVERNOR.—The part shown just to the left of the pump. It is designed to shut off the steam supply to the pump when a predetermined air pressure has been obtained.

AIR PUMP.—It is shown at the extreme right of Plate A. The top or steam piston actuates the lower or air piston, which latter compresses air on one side, while on the other, air at atmospheric pressure is being drawn in. The air compressed lifts one of the discharge valves and passes on to the main reservoir, from which point it passes through the brake valve into the brake system at the discretion of the engineer.

MAIN RESERVOIR.—The one usually placed upon the engine, in which a large supply of air is stored for the purpose of releasing the brakes and recharging the brake system when so desired. Air for the signal system is also taken from the main reservoir.

WESTINGHOUSE AIR-SIGNAL EQUIPMENT.

The compressed-air train air-signalling apparatus has become one of the indispensable conveniences in passenger railway service.

It consists of a pipe extending from the main reservoir on the engine to a reducing valve (Fig. 430) which reduces the main reservoir pressure to 40 pounds, the amount used in the

signal system. From the reducing valve the air flows to a tee, one branch of which leads to the signal valve (Fig. 431), and the other to a separate pipe which passes back to the end of the train. On each car is placed a discharge valve to which a cord, running the full length of each car, is attached.

The pressure in chambers *A* and *B* (Fig. 431) equalizes, being connected by a slightly loose fit of stem 10 in bushing 9. In response to the reduction of signal-line pressure, made when the discharge valve on a car is opened, a reduction wave

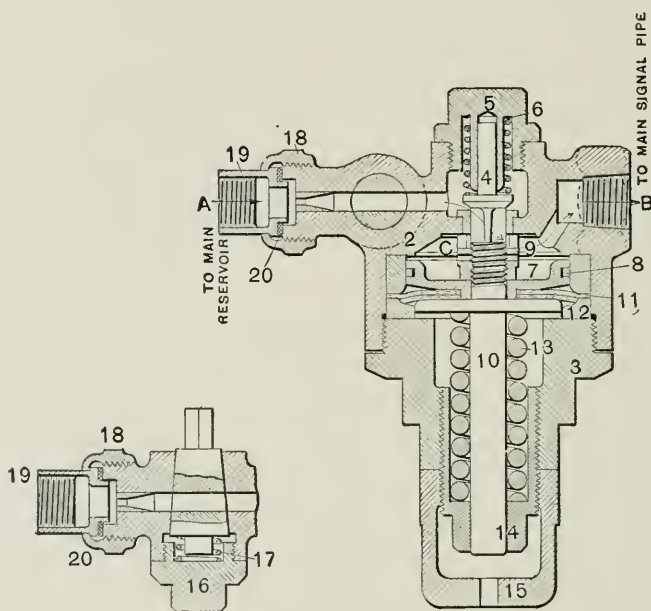


FIG. 430.- SIGNAL REDUCING VALVE.

is carried to the signal valve, where it first manifests itself in chamber *A*. The greater pressure in chamber *B* raises the diaphragm 12 and stem 10, thus unseating the valve at the end of stem 10, and air escapes at *X* through a pipe leading to a small whistle, located conveniently close to the engineer, causing it to blow.

This same reduction wave causes the reducing valve to open, and the air from the main reservoir entering the signal line causes the pressure in chamber *A* (Fig. 431) to increase and

force the diaphragm down again, closing the valve at the end of stem 10. It is then only necessary to wait two or three seconds to allow the pressure to equalize throughout the signal system, when another signal may be given.

AIR BRAKES FOR TROLLEY CARS.

Compressed air is largely in use for air brakes on trolley and cable cars, the air being compressed by direct connection from the piston to a cam on the axle, by a reducing gear from

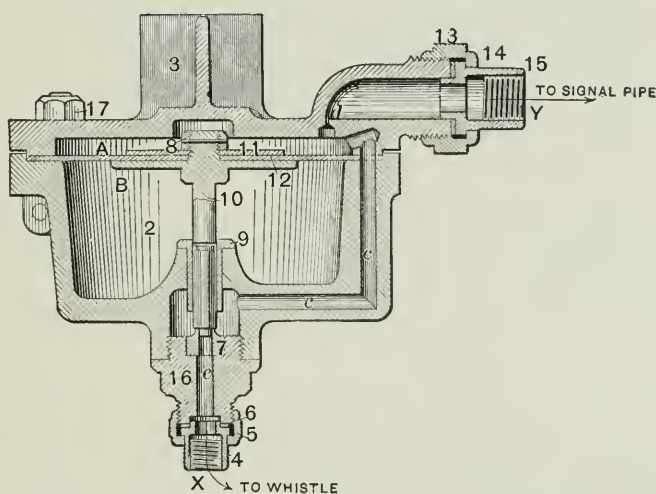


FIG. 431.--SIGNAL VALVE.

the axle, or by an electric motor when available. This system has been placed on many of the trolley roads in the United States and in Europe by the Standard Air Brake Company of New York.

In operating brake mechanism by compressed air obtained through the action of their air-compressor operated from the axle of the car, it is necessary to stop the compressor's action when the air has been compressed to a predetermined limit, in order that the compressor may continue to run with the axle but without absorbing power. This is accomplished as follows: as long as the air has not reached the set pressure to be carried, the com-

pressor forces air through the discharge valve direct to the reservoir, and will continue so to do until the required pressure is reached. The pressure will then open a regulator valve and admit air under a diaphragm, forcing upward the governing piston and lifting the suction valve from its seat.

This allows the compressor piston to move freely, and prevents it from doing any work until, by application of the air to a brake-cylinder, the pressure is reduced.

The reduction of pressure, acting upon the regulator, releases the air confined under the diaphragm, and allows the governing piston to fall, reseats the valve, and the compressor resumes furnishing pressure.

In making a stop, only two or three pounds of registered air pressure is required. This the compressor furnishes in a very short travel of car. The reservoirs hold in reserve several times the amount of air required to stop the car, even without additional supply. The air pressure is thus practically inexhaustible under the conditions of operation.

When the direct or geared axle-driven compressor is used, enough compressed air is automatically maintained in the reservoir to admit of frequent stops.

The electric compressor does not depend upon the car axle; it is entirely disconnected therefrom. The motor is operated by the trolley current only when necessary to maintain proper pressure in the storage reservoir. All the working parts of these compressors are enclosed. It is only necessary to lubricate regularly. The construction resembles that of the modern enclosed motor in that slush, water, and dirt are excluded.

The electric compressor acts substantially similar to the other, in so far as relates to the regulating of reservoir pressure. The automatic current controller, however, puts the electric compressor in or out of service, according as the air supply in the reservoir increases or diminishes.

The electric compressor may be placed anywhere on a car, under, inside, or outside.

THE LOCOMOTIVE BELL-RINGER.

If you wish to hear locomotive bells rung by compressed air, you must take a train on the Kansas City, St. Joseph & Council Bluffs Railway, on which line a number of pneumatic bell-ringers are in operation, giving admirable results.

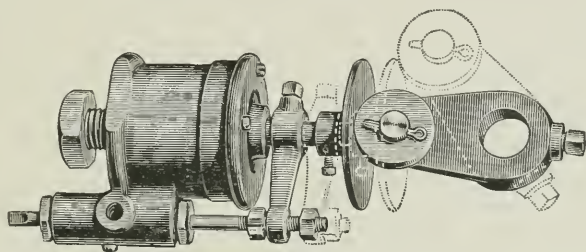


FIG. 432.—PNEUMATIC BELL-RINGER.

It is attached to the air-pump receiver on a locomotive, and by the automatic vibration of the air piston it operates the bell crank and rings the bell.

Chapter XXVII.

PNEUMATIC WORK

PNEUMATIC WORK.

PNEUMATIC SHEEP-SHEARING.

MANY attempts to perfect a mechanical device which would lighten the work for the shearer, prevent the wool from being injured by second cuts, and guarantee the next fleece to be even in length, or "wool-topped," have in the past twenty years been made. But it was only when the "Australian Shearer" made its appearance that the wool-growers and shearers gave the hand-shearing entirely up.

In Fig. 433 is represented an English compressed-air sheep-shearing machine. A small piston vibrates and operates the cutters through a lever with a diagonal slot in which a pin in the piston-rod head slides. An arm on the piston rod operates the valves at the end of each stroke.

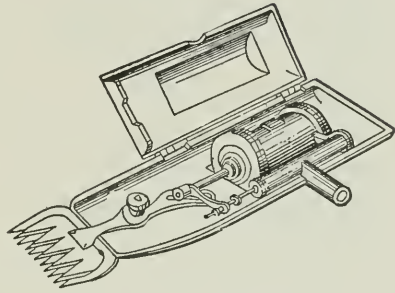


FIG. 433.—SHEEP-SHEARER.

The Australian sheep-shearing machine (Fig. 434) is exceedingly simple, direct-acting, and easy to handle. It is composed

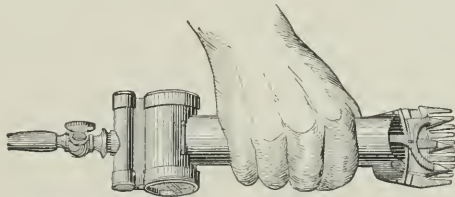


FIG. 434.—AUSTRALIAN SHEEP-SHEARER.

of eight pieces: The body of the shearer, the oscillating fork, the piston, the valve, the comb, the cutter, the piston covers,

and the tightening ratchet. The valve is entirely balanced. The motion of the machine, similar to that of a rock drill, is given by the piston, which is $1\frac{5}{8}$ -inch diameter, $\frac{5}{8}$ -inch stroke. The fork is centred on a half-round bearing, the cup of which forms an oil receptacle, so that the bearing is all the time working in a bath of oil, reducing the friction. The pressure-nut, which regulates the pressure of the cutter on the comb, is inside of the body of the machine, so that it cannot interfere with or tear the fleece during work. The machine having no perceptible vibration, as can be proved by laying it down on the floor while running at full speed, the wrist of the operator is not subjected to any strain. The weight of the machine is 2 pounds 2 ounces, and this being counterbalanced, the shearer has neither strain nor weight to overcome. The motive power is air under a pressure of about 40 pounds to the square inch, which is conveyed to the machine through a rubber tube $\frac{1}{4}$ inch in diameter. Each machine uses 15 cubic feet free air per minute. The absence of joints and complications permits the shearer to work in any position he desires. The machine makes 6,000 oscillations per minute, but does not run hot, as the exhausted compressed air passes through the hollow casing of the body and escapes over the cutter, keeping the fleece well before the points of the comb, enabling the shearer to watch the operation, and at the same time keeping the machine cool while in his hands.

The inconvenience of the heat and the disadvantage of the friction which causes the heat and increases the wear and tear, involving cost of repairs and fear of delay at shearing time, are thus obviated. The simplicity of the construction dispenses with the necessity of skilled labor in setting up, adjusting, or running the machine.

The use of this machine reduces the time of shearing from an average of 70 sheep by hand to about 100 per day of ten hours. At Barsham, in Australia, three men sheared 334 sheep with this machine in ten hours, the third day they ever handled

machines. Furthermore, the "Australian Shearer" saves about three-quarters of a pound of fleece wool per sheep, a profit of about 16 cents; and as the wool is worth 1 cent a pound more when cut in this way, as it is longer and more uniform in length, than by hand shearing, this would, with an average yield per sheep of about 8 pounds of wool, bring the total profit by the use of this method up to 24 cents per sheep.

Another point in favor of this machine is that by its use the animals are never mutilated.

They are made by Rochet & Company, Paris, France.

COMPRESSED AIR IN A SAW-MILL.

The power that operates a saw-mill, be it steam or water, is utilized for compressing air to operate the various saw-mill appliances that both steam and water are unfitted for, from the trouble of condensing steam in interrupted use and the liability of water to freeze in cold weather. The log-flipper for rolling logs out of the log slide, shown in Fig. 435, and the nigger for rolling and turning logs on the saw-carriage (Fig. 436) are some of the new uses for compressed air. These devices, together with a jump saw for cutting logs to the proper length, and a saw-feed motor, all driven by compressed air, are in successful operation at the Engel Saw-Mill, Orono, Me.

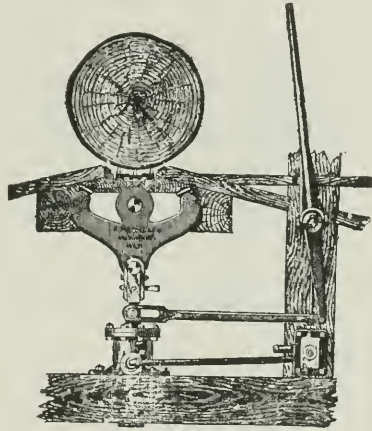


FIG. 435.—LOG FLIPPER.

COMPRESSED AIR IN BASKET-MAKING.

Take the work of basket-making. Surely, no one ever heard of any of the old machines turning out 180 bushel-baskets per hour, or 1,800 baskets per day, but a compressed-air basket-making machine is now doing it at the Michigan Avenue fac-

tory, Traverse City, Mich. The staves of the baskets are fastened to the hoops by staples of wire taken from the coil, joined and driven by the machine. The staves radiate from a centre in a disc-like shape. To bend them into the lines of the basket form, four processes or movements are made by the machine, all of which are automatic and obtained by the medium

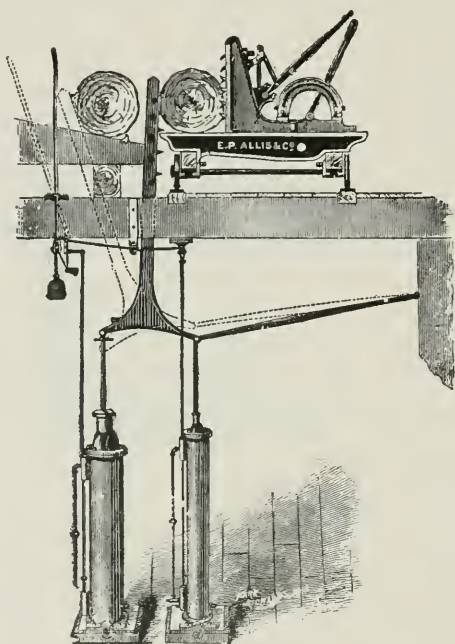


FIG. 436.—PNEUMATIC NIGGER.

of compressed air. The whole combination is very simple. The air is not cooled, and the machine runs ten hours every working day.

THE AIR-BRUSH.

Then there is the fountain air-brush, which some claim will soon be adopted by the leading artists for applying color on canvas. It is shaped like and is but little larger than a lead pencil, is handled in the same man-

ner, applies color in large quantities in a short time, and is yet adjustable for the finest line ever drawn on canvas by a gifted artist.

COMPRESSED AIR FOR BLOWING YACHT AND LAUNCH WHISTLES.

To the water sportsman there is nothing more pleasing than a well-toned air-whistle for signalling. The push and draw whistle, at the hand of the wheelman, by intelligent manipulation can be made not only to give the ordinary signals for navigation, but can be operated telegraphically for other communications.

A small air tank under the forward deck may be charged by an air pump operated by the propelling engine, and will store air sufficient for operating the whistle when the boat is not

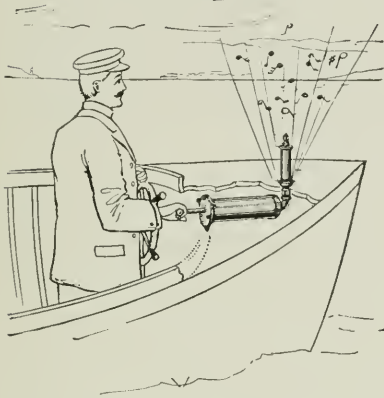


FIG. 437.—PUSH WHISTLE.

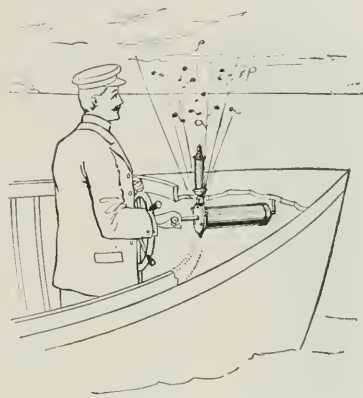


FIG. 438.—PULL WHISTLE.

running. They are furnished by the Gleason-Peters Air-Pump Company, New York City.

COMPRESSED AIR FOR BLOWING FOG SIGNALS.

The United States Lighthouse Department has for some time devoted much attention to the improvement of its fog signals, and to that end has recently adopted compressed air in place of steam for sounding fog signals. A very compact plant has been developed for this service, and one is now installed at Montauk Point, on the extreme eastern end of Long Island. The motive power is furnished by a ten-horse-power Hornsby-Akroyd oil engine, which drives an Ingersoll-Sergeant Class E air compressor. The oil engine occupies a floor space of 9 feet 2 inches by 5 feet. The air compressor has a base measuring 6 feet by 2 feet 1 inch, and is capable of furnishing

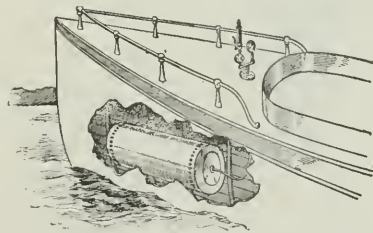


FIG. 439.—AIR TANK AND WHISTLE.

107 cubic feet of free air per minute at 150 revolutions. The air is compressed and delivered to a receiver at 50 pounds pressure. It is then carried to another receiver about 200 feet distant. Midway on the pipe line a reducing valve regulates the pressure and admits it to the second receiver at 30 pounds pressure. This receiver holds the immediate supply of air to operate the trumpet.

Exhausting through the siren at this lower pressure enables the receiver to maintain the supply after a fog rises for a time sufficient to get the engine and compressor in operation. There are two trumpets attached to the receiver, which are used together or alternately, as desired. A first-class siren is supposed to consume 12 cubic feet of free air per second.

The siren is sounded automatically, and blows at intervals of 30 to 50 seconds. As a musical instrument it can be best described by calling it a big clarionet.

The Daboll trumpet is another fog signal similar in general design, but having a smaller range of audibility, and requiring less power. The plant used consists of a four horse-power engine and a vertical belt-driven compressor furnishing 17 to 20 cubic feet of free air per minute. It delivers air at a pressure of from 5 to 10 pounds to a receiver which supplies the trumpet.

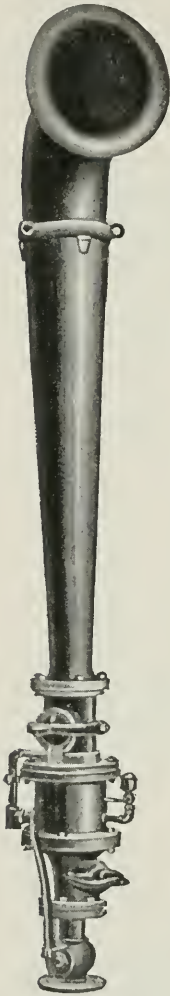


FIG. 440.—SIREN.

The importance of conveying sound or a signal to a greater distance than heretofore in a fog or in thick weather at night, has long been felt, and at last the want has been met in the production of the "Brown" fog-horn or siren, which is illustrated in Fig. 440. It consists of a chamber containing a peculiar mechanism for producing a large volume of

sound in the vibration of the air passing the mechanism, and which is still further strengthened by the immense trumpet that surmounts the chamber. It seems to fulfil all the conditions required on shipboard, at lighthouses, and on lightships. It has been heard a distance of 31 miles on the open ocean. It requires about 80 pounds pressure for its best work. When steam is used, a drip pipe is inserted in the chamber to drain off any water that may be condensed in the apparatus by leakage of steam through the valve. On the lightship off Sandy Hook, New York harbor, the air is compressed by a kerosene engine and stored in receivers for ready use in the siren.

COMPRESSED AIR FOR RAISING SUNKEN VESSELS.

The use of air pumped beneath the sealed decks of sunken vessels for raising them has been in successful practice for

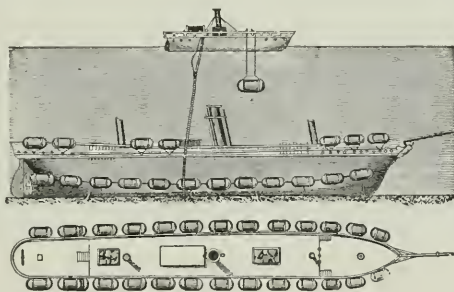


FIG. 441.—THE AIR-CASK SYSTEM.

many years. Casks or bags placed on the inside or fastened to the outside, and inflated by pumping air into them, has been the means of saving many vessels that otherwise would have been a total loss. Long iron tanks have been floated to the sides of a sunken vessel and filled with water sufficient to sink them, when they are attached to the side of the vessel and air pumped in to displace the water. The buoyancy of the air tanks raised the vessel to or near the surface for towage to a shelter. By placing the air-bags under the deck, the schooner *Glenola* was raised in Great South Bay, also a vessel in Puget

Sound. Failures have been made by filling the bags or casks with too much air, which expands in rising from deep water and bursts its enclosure. Air vents at the bottom of each bag or cask are safety-valves for deep-water work by compressed air.

The bursting of the air bags has been the cause of failure in the early work of raising vessels by compressed air. Colonel Gowan met this difficulty in the attempt to raise the United States steamer *Missouri* at Gibraltar in 1845. He tried it at

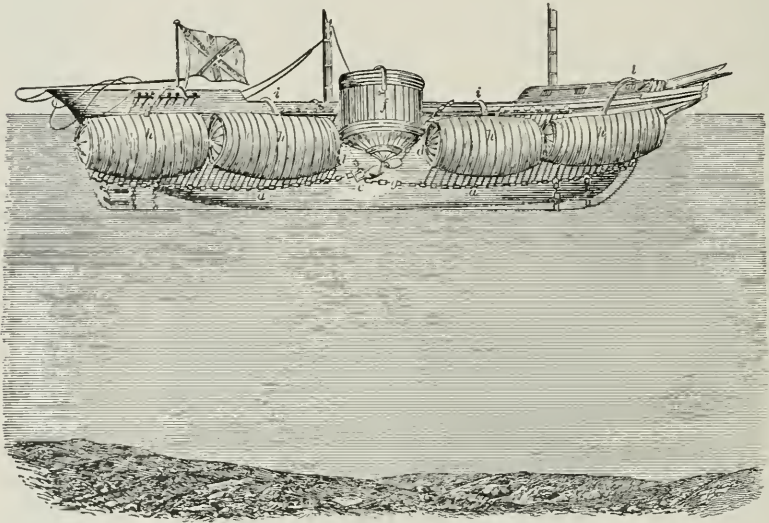


FIG. 442.—THE AIR-BAG SYSTEM.

Sebastopol, but failed at first. A combination of floats and compressed air finally made a success in raising nearly one hundred vessels.

Fig. 442 represents Captain Austin's plan, in which the large inflatable canvas bags, *h, h, h*, in the cut, were rendered water and air proof by india-rubber and strengthened by envelopes of netting. Chains were swept under the vessel and fastened to horizontal chains to which the air bags were lashed. Air was pumped in through the air pipes, *i, i, i*, allowing for sufficient expansion of the air as the vessel rose.

Compressed air played a most important part in the raising

and floating of the steamer *Plymouth* from the rocks in the harbor of Newport, R. I. The steamer had double hulls with compartments between the hulls, which were ruptured by the vessel running upon the rocks, and many of the partitions between the compartments were injured so as to cause leakage into a large portion of the space between the hulls.

It was found that the pontoons and derricks could not lift the vessel sufficiently to clear the rocks, and recourse was had to pumping air into the compartments by a compressor utilized for the purpose, which forced the air throughout the compartments through the drainage-pump pipes and thus added about 400 tons to the lifting power of the derricks and pontoons. It was found after floating the steamer that the air compressor was able to keep her afloat without the pontoons and derricks, which were then unshipped and the vessel was towed up to Newport.

COMPRESSED AIR IN SUBMARINE EXPLORATION.

There is no condition of the relation of compressed air to human vitality more delicate and important than when a man dressed in a diver's close-fitting armor descends to the bottom of the sea.

The sudden change of atmospheric effect upon his system by great pressure in descent, and its release in ascent, calls for great caution as to the time required for the change in pressure, as well as an experienced practice by degrees in depth, combined with a strong vitality in the person, before excessive depths can be accomplished and work performed. The least mishap may be fatal, yet there are men who have practised this work for many years without accident or material deterioration in health.

The usual work of the diver is under 100 feet in depth; seldom 150 feet; and the greatest depth that has ever been reached by a diver is 204 feet, requiring an air pressure of $88\frac{1}{2}$ pounds to balance the water pressure.

The armor consists of a helmet to protect the head; a dress, of canvas and rubber, attached to the helmet; shoes, with lead soles, to keep the feet down and the body upright; lead weights to sink the diver to the bottom, and to prevent his rising from an over-pressure of air from the air-pump. A life or signal line is used for lowering and raising the diver, and for the transmission of signals between the diver and his attendant.



FIG. 443.—SUBMARINE EXPLORATION.

The diver, being dressed in his flannels, is now equipped with his dress; the air-hose is screwed to the helmet and air-pump, the pump started and the headpiece screwed on, and he is lowered to the bottom, where he can remain from one to six hours, according to the depth of water, the speed of the tide, and the character of the work.

The helmet is the most important individual piece in the

outfit, for to it is attached the regulating valve seen at the right side of the helmet in Fig. 444, and in reach of the diver's hand, allowing him to adjust the escape of air to suit the needs of respiration, irrespective of the automatic air escape.



FIG. 444.—THE DIVER IN ARMOR.

This helmet has the latest improvements in the addition of the top glass that the diver may look upward without throwing the body back. A telephone attached to the helmet is a late and important addition to the facilities for operating in sub-

marine work. A transmitter and receiver are fixed on the inside of the helmet and connected by insulated wires with their counterpart in the hands of the attendant, by which orders and information may be quickly passed, which has been a most tedious process under the old jerk-cord system.

The amount of free air required by a diver varies somewhat under the varying pressure in which he is operating and of habit in respiration. And as a man in normal condition makes

about 16 respirations per minute with an average of 40 cubic inches at each respiration, it will require nearly half a cubic foot of free air per minute for respiration alone, and for exhausting the vapors from the body as much more, or, say, a cubic foot per minute.

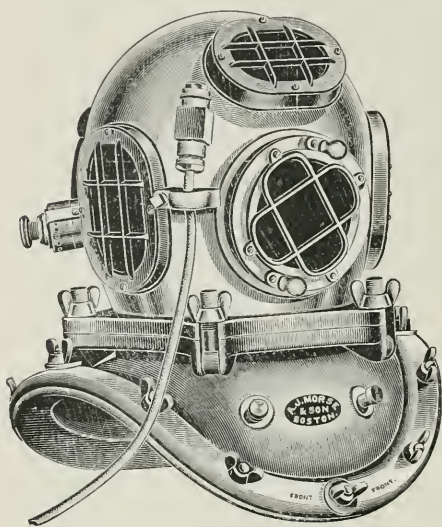


FIG. 445.—THE HELMET.

In Fig. 446 is illustrated a submarine air-pump, double-acting, single cylinder, of capacity for one

diver at ordinary depths, and to 100 feet water pressure. It is furnished with a water cistern for cooling the compressed air, and a pressure gauge.

The above submarine apparatus is manufactured by A. J. Morse & Son, Boston, Mass. Their catalogue contains interesting details in regard to management in the use of submarine armor, habits and living of divers, and their health.

COMPRESSED AIR FOR DREDGING CHANNELS.

Dredging experiments have been made, especially in England, Holland, and the United States, with apparatus designed for digging up alluvium, dissolving in water the materials of

which it consists, and giving these up to natural currents when the latter have their greatest strength. Such experiments, however, have not given satisfactory results, since the materials thus dredged were lifted but to a small distance from the bottom from which they had been extracted, and thus almost immediately settled back again in the same place. Although this

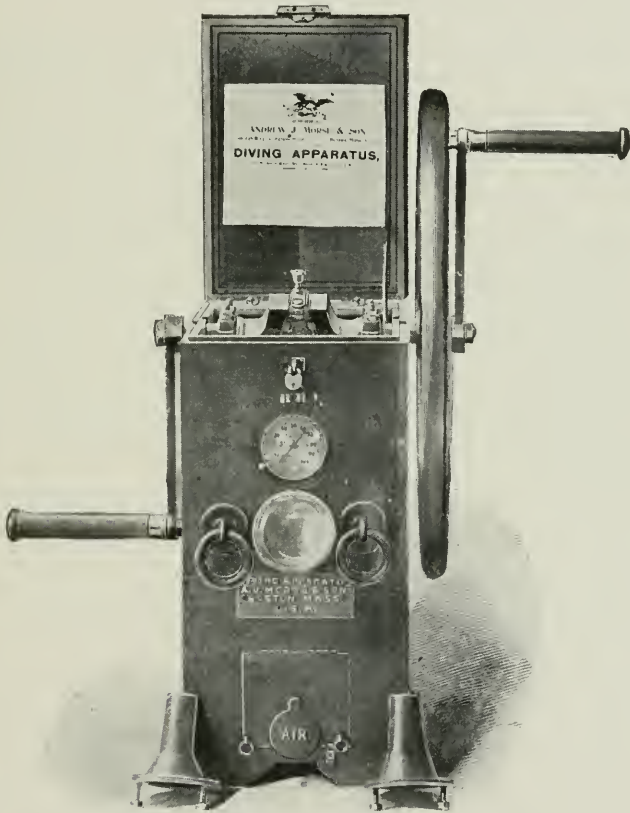


FIG. 446.—SINGLE-CYLINDER DOUBLE-ACTING AIR PUMP.

mode of dredging had therefore to be given up, it has been successfully taken up by Mr. Meinesz, who employs compressed air for forcing to the surface the material that has been detached by means of a kind of harrow, in order to put it thus in contact with as great a number of molecules of water as possible and to give it a velocity in a direction opposite that of grav-

ity. Once raised to the surface of the water, the sands are carried off by the current to distances which vary according to the swiftness of the current and to the depth from which they have been dredged. The whole question, then, resolves itself into a study of the direction and force of the current, so that the deposits shall be borne away as far as possible from the channel that it is desired to excavate.

A late innovation upon the old system of operating the clam-shell bucket by chains, has been made by substituting a cylinder and piston moved by compressed air for opening and closing the bucket; the action being wholly independent of the hoisting chains and of the position of the bucket. The hose for operating the piston is wound on a counterbalanced reel and is carried freely by the movement of the bucket.

The advantages claimed are a wider scope to the action of the bucket and the utilization of the full weight of the bucket and air cylinder to produce a full-depth scoop of the bucket, which in the old way was lessened by the pull of the bucket-closing chain.

Chapter XXVIII.
PNEUMATIC WORK—Continued

PNEUMATIC WORK.

(Continued.)

THE COMPRESSED-AIR BLAST.

AN interesting application of the use of compressed air is that of the Fallbrook Railway Shops in furnishing a blast for the boiler-makers' forges. The driving rig was removed from an ordinary portable forge (Fig. 447), and the nozzle *B* was screwed in the shell so that the air current would impinge on the vanes of the fan *A*. The amount of throttle opening required is very small to drive the fan at a high rate of speed, so that it is remarkably economical of air. The blast furnished is almost an ideal one for this purpose, and one capable of the closest regulation.

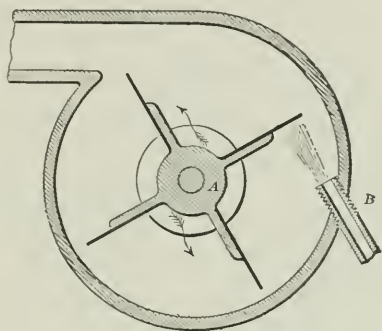


FIG. 447.—INDUCED AIR BLAST.

By the device illustrated in Fig. 447 the compressed air supplies a blast of many times its own volume, and with all the pressure required.

The compressed-air injector is illustrated in Fig. 448. The fact is well known that the principle of action of the steam injector and ejector may be applied to air for forcing a larger volume at a less pressure into a receiver for any use, and especially for ventilation.

Experiments have shown that one volume of air when passed through a nozzle as at *C* (Fig. 448), when the apparatus is arranged as an injector, at a pressure of 5 pounds per square inch, will induce 30 volumes of free air as measured by a meter. Air under pressure will discharge through a nozzle of

best form at a velocity of about 650 feet per second; it is easy to understand that free air will be induced and discharged with it into a secondary receiver. Such an arrangement is shown in the cut (Fig. 448), in which *B* is the receiver, *D* the induced current nozzle, *A C* the compressed-air nozzle, *E* the air chamber, and *F* a light check and free-air inlet.

This air injector has been tried with success, though the experiments have not gone far enough to determine to what extent it will effect a saving in the production of pneumatic

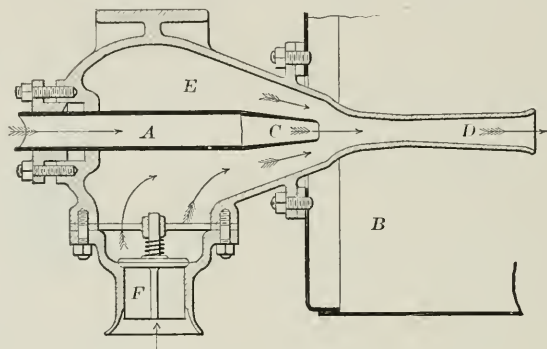


FIG. 448.—THE COMPRESSED-AIR INJECTOR.

power. It has been found that with a pressure of 80 pounds in the first receiver, the injector will work discharging and inducing free air into a second receiver in which is maintained a pressure of 60 pounds.

THE SAND BLAST.

The energy contained in a single flying grain of sand is small, even when travelling at a very considerable velocity, but it is the exceedingly small area upon which this is expended that makes any cutting by it possible. As an illustration of the above points, take, for instance, the case of a sand blast using sand of an average of $\frac{1}{50}$ inch in diameter and propelled by air of 50 pounds to the square inch, cutting granite. Such a blast, under these circumstances, will cut granite rapidly. Why? Determining the above factors, first, such sand

grains will weigh on an average about 0.005 grain and will be moving at the point of impact with the stone about 400 feet per second, and will therefore contain about 0.00176 foot-pound energy. Now, this is certainly a very small amount, but next take the area upon which it is expended.

The area of first impact can only be estimated from the following considerations: If a piece of smooth, hard substance is scratched with the edge of crystal, as, for instance, in ruling diffraction gratings and that class of work, lines are readily ruled at the rate of .00002 to the inch, and when examined under the microscope the lines are seen to be narrow in comparison to the space separating them, being themselves probably not more than $\frac{1}{50000}$ inch broad, and it is upon a rectangle of the length of side equal to the breadth of one of these lines that the first impact occurs. This is .00000004 square inch. And the above-determined 0.00176 foot pound of energy distributed upon this area is at the rate of 440,000 foot pounds per square inch. Now, the strongest granite can stand only a quiet crushing strain of some 1,200 tons per square foot, or at the rate of some 16,600 pounds to the square inch. The contest between the stress developed at the point of impact and the resistance of this object struck is in this case decided overwhelmingly in favor of the stress developed. The result is that the granite under the point of the first impact is crushed and crumbled to dust, letting the grain of sand progress until in its advance it has expended its energy and increased the area of contact, when the pressure there falls below the crushing strength of the granite, and then the action of that grain is over and it rebounds from the stone. The striking edge or point of the grain of sand is also crushed, and contributes to increasing the area of contact between it and the granite. The effect of the above sand blast, when striking a piece of wrought iron in place of the granite, will be that the iron, instead of being pulverized like the granite, is only indented. The result is that no metal is removed, but a small indentation produced. Other grains

striking in the immediate vicinity of this indentation simply shove the metal back into it again and obliterate the effect of the first grain. Thus no effect is produced, but the surface is simply roughened by the indentations of the sand grains. This is the normal effect of the blast upon all metals. If they are exposed for a long time to the action of the sand, as in a sand-blast machine, metals wear away, because the surface metal is exhausted by the constant bending so that it at last breaks. If the blast is directed upon a piece of soft rubber the same action as in the case of the metal takes place, but in this case the elasticity of the rubber is such as to enable it to resume its original shape after the force of the impact has been expended in deforming it, and there is no residual effect whatever upon the rubber, the grain of sand rebounding with almost its original velocity. These three actions and the combinations of them explain all the different effects of the sand blast, in cutting and refusing to cut various substances.

In surface obscuring or ornamenting, such as in glass work, for which the sand blast has been more used than for all other purposes combined, the problem is entirely different. The effect wanted is to break the continuity of the surface struck, and this once obtained any further force in the blow of the sand is wasted, and an exceedingly great number of light blows is what is desired. Therefore a very fine sand is used and a large quantity thrown in proportion to the propelling jet, which gives a moderate velocity. So important is the adaptation of the size of sand to the work that if two exactly similar machines are taken, one using fine and the other coarse sand, and both using the same pressure of air to drive the sand and the same size jet, the machine using fine sand will obscure three times the work that the machine using coarse sand will do. But in cutting or perforating glass or stone the machine using coarse sand will do three times the work of the machine using fine sand. In one case the blows are too few to break up much surface, and in the other case they are too light to do much cut-

ting. Thus, by use of sand unsuited to the work, the efficiency of a good machine can be reduced over 60 per cent.

THE SAND BLAST AND ITS WORK.

The economy of the sand blast to lighten the labor of cleaning castings in the foundry is a most important use of air apart from the melting blast. With it, the air hoist, the moulding machine, and the air lift, and we may add the air rammer, have brought the work of the foundry to a high degree of perfection and economy in their labor-saving aspects. On an average it

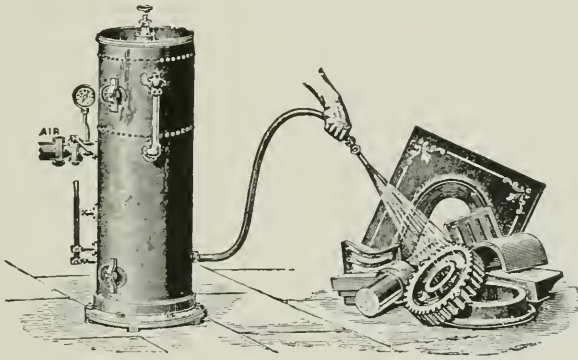


FIG. 449.—WARD & NASH APPARATUS.

now takes but one-third of the time to clean a casting or the day's run, as was formerly the case by hand.

Neither files nor brushes can get around recesses, fins, and risers as the blast does, and when so cleaned the air-chipping hammer has a clean path for work.

In Fig. 449 is illustrated the Ward & Nash sand-blast apparatus at work. The sand is fed to the air pipe as shown in Fig. 450, and carried through a short rubber hose and ejected through a nozzle at great velocity, estimated at from 350 to 500 feet per second. At this great velocity the sand has an intense cutting power.

For small castings suitable for the tumbling barrel, the sand blast facilitates and preserves the sharp corners of castings to a

marvellous extent. The barrel used for this work is open at both ends and revolves on rollers; the sand blast enters at one or both ends of the barrel, while it slowly rolls the castings over. In the detail of the sand tank (Fig. 450) the compressed air enters the lower compartment at *B*, and issuing through the cross pipe *D* receives its charge of sand graduated by the slide valve *F*, which is regulated by the lever *E*. *C C* is the conical partition that holds the sand in the upper chamber. *A* is the inlet valve held in place by a spring. The upper section is the hopper into which the sand is dumped, when by pushing down the spring with the valve *F* closed the sand drops into the feed chamber.

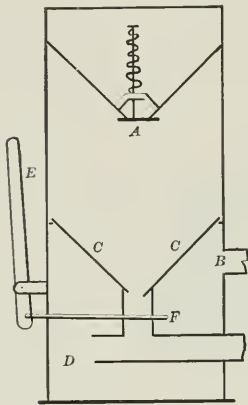


FIG. 450.—SAND-BLAST TANK.

For the foundry sand blast an air pressure of 25 pounds per square inch seems to meet the requirement; but where hoists, hammer-chipping tools, and rammers are used that require higher pressure, the sand-blast pressure can be readily throttled to the requirement of its best work.

For the different uses of the sand blast the abrasive substances may be clean silicious sand as builders' sand, sea-beach sand, emery from fine to coarse, chilled iron sand, and steel shot; sand from its plenteousness and general suitability is mostly employed. The heavier material, as emery and chilled iron, require higher air pressure to give the best cutting velocity.

The action of the sand blast is not cutting, not grinding, not abrading in any of the usual meaning of these terms. It is a true pulverization by the successive impact of the grains of flying sand. The sand acts much in the same manner, but on an infinitely reduced scale, as artillery projectiles in breaching a masonry wall, each independently of all the rest. In this action it differs from anything that has preceded it, and it still

stands alone. It is this difference between its action and all other processes that has caused the general misunderstanding about it above referred to. As all know, the process consists simply in driving a stream of rapidly moving sand against the object to be operated upon. How the sand is given velocity, or how the work is presented to the blast, are matters of indifference when examining the theory of the process. As the total action of the blast is but the summation of the action of the individual grains, the action of the individual grain is to be considered. If the single grain of the flying sand has no effect when it strikes the work, then no other grains will have any, and the sand blast will be without effect, no matter how long continued. If, however, the single grain of sand has any effect upon the object struck, then the blast will wear it away, often at an extraordinary speed, as the number of grains propelled against it is very large, often as many as 5,000,000 per minute.

Grains of sand have numerous angles, and the action of these grains—as also that of the other abrasives mentioned—upon the surfaces of glass, stone, or metal, is due to the circumstance that every individual grain in the incessant infinite number in the stream urged violently forward has all its energy instantly arrested, transferred, and concentrated upon its point of impact, where it produces a minute pit or depression; and, as every grain in the shower acts alike, the abrasion resulting from the whole is perfectly uniform in depth and texture or roughness.

The action, moreover, is extremely rapid; a momentary application depolishes glass over any space that can be covered by one stroke of the sand shower, instantly changing the previously bright surface to obscured or that known as ground glass. A little longer exposure cuts more deeply, and, with further time, apertures are readily pierced through sheet and plate glass.

Stone, marble, slate, and granite are just as amenable to its action. Iron, steel, and other metals have their surfaces easily

reduced, and smoothly or coarsely granulated, according to the force and abrasive power used; but all these materials, being less brittle than glass, take a rather longer time. Speaking generally, it appears that the harder or more dense the material acted upon, and the higher the velocity given to the sand, the

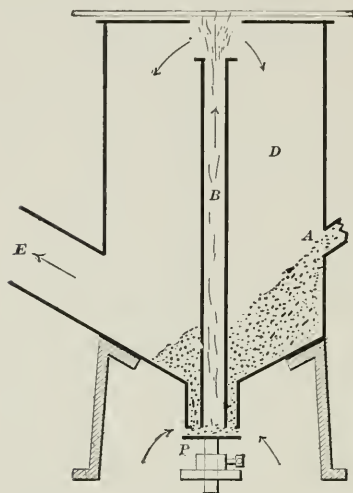


FIG. 451.—EXHAUST SAND BLAST.

more rapid the cutting action; and the finer the abrasion, and the lower the pressure of the air, the finer the granulation produced. It is also remarkable, that it is by no means necessary that the abrasive be harder than the material to which it is applied; thus, hardened steel and corundum are readily pierced with sand.

This granulating, scaling, incising, and piercing, however, is but one-half of the process, for, if the work be partly covered and protected by some slightly yield-

ing but tough substance, adhesive or in the form of a metal template lying closely upon it, this interposed substance instantly diffuses the shock of the particles and neutralizes their abrasive power. The action of the sand blast is thus confined to the unprotected portions of the surface, and these overlays and templates are used on glass, stone, slate, pottery, and metal for surface ornamentation, for deeper intaglio and perforations.

An early exhaust-air sand-blast machine is illustrated in Fig. 451. It had a closed iron drum *D*, about 20 inches diameter, with an open central pipe *B*, and below the latter a vertically adjustable plate *P*. The head of the drum had an aperture about 4 inches in diameter, closed by the work, overlay downward, lying upon it, the exhaust being at *E*. The sand from a closed box falls down the pipe *A* to the bottom of the drum, on to the plate *P*; thence impelled or sucked up the blast

pipe *B* by the external air rushing in above the plate *P*, it strikes the work, which is moved about by the operator, who looks through the glass to watch the progress of its frosting. Most of the sand falls back to the bottom of the drum; some, with the dust pulverized from the glass, is carried along the exhaust to a sand-catch box. The air pressure need not exceed one pound to the square inch, the frosting is almost instantaneous, and the hand may be held in the blast without inconvenience. Several machines are connected to one exhaust running round the workshop; they are used for small work, but are applicable to sheets as large as can be conveniently moved about by two men.

A small vacuum or exhaust sand blast is shown in Fig. 452. It has a bellows formed of a heavy plunger *A* connected to the sides of the drum by an india-rubber apron or diaphragm and by a cord to a lever, by which it is operated like a suction bellows, the valve *E* acting as the discharge valve. The base of the blast pipe, of $1\frac{1}{2}$ inches bore, is surrounded by a cup, *S*, pierced with holes below, and beneath there is a vertically adjustable plate or disc. The sand placed in *S* falls on the plate, and is carried up by the inrush of air between that and the lower end of the blast pipe to strike the work; it then falls and collects in the base of the drum. The plunger is raised for every impression, the lever being worked by an assistant, sometimes by standing his weight upon it; in smaller machines, it is placed close to the blast, and worked by the left hand, and the objects to be frosted are changed by the right.

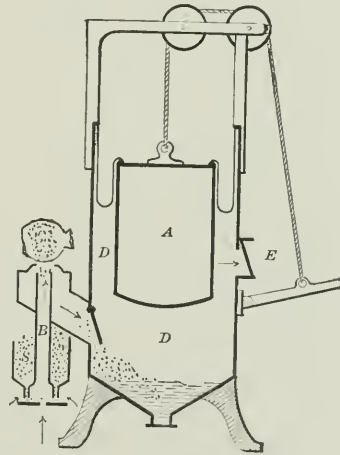


FIG. 452.—EXHAUST SAND BLAST.

A form of exhaust-air sand-blast machine is shown in Fig. 453, in which the drum has a large exhaust chamber, *E*, open

below and worked from above; *D* also carries the sand, which falls through a pipe, regulated by a valve, into the open end of

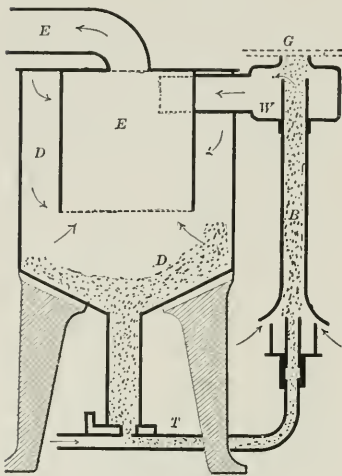


FIG. 453.—VACUUM SAND BLAST.

the tube, *T*, $1\frac{1}{2}$ inches diameter, which, bent upward, terminates within the open bell mouth of the lower end of the blast pipe *B*, 2 inches diameter, outside the drum. The upper end of *B* is contained within a box, called the working chamber, provided with an aperture above, upon which the glass is placed. The sand carried up *T*, by the current induced by the exhaust, as it issues is caught by the stronger current of external air entering all around the open bell mouth of *B*, and thus accelerated travels upward and strikes the work. The exhaust then carries the spent air and sand from the working chamber, *W*, to the annular space *D*; here both circulate spirally around, and to the bottom of *E*, the heavier particles of sand striking the sides of *D* by centrifugal force, and falling to the bottom, the lighter particles and the dust pulverized from the glass, travelling with the air up within *E*, and along the exhaust pipe *E*. Virtually free from the escape of sand, the machine almost entirely sifts the dust from the sand, which latter is used again and again. Large sheets of glazing glass, covered with their overlay designs, are thus frosted to the form of the pattern.

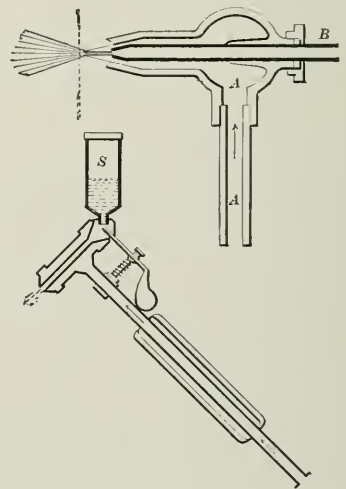


FIG. 454.—PRESSURE SAND BLAST.

In Fig. 454 are represented two forms of pressure air sand-

blast nozzles. These nozzles have been made as round and flat blast pipes, which postpone the mingling of the air with the sand until both have issued from the nozzle. The straight pipe in the upper portion of Fig. 454 represents the pipe through which the sand arrives by gravity or otherwise; this is surrounded by the enlarged hollow head of the air pipe, *A*, the one adjustable lengthwise within the other to determine the extent of the annular space between their open tapering ends; the air rushing up *A* issues through this space, and, converging, catches up and carries the sand forward, the two only mingling at the point shown by the vertical dotted line, well beyond the end of the nozzle.

The lower figure represents this principle with a sand box and valve attached which can be operated by the thumb as the hand grasps the handle.

A form of sand-blast cylinder which allows of recharging without interrupting the operation of the sand blast is illustrated in Fig. 455.

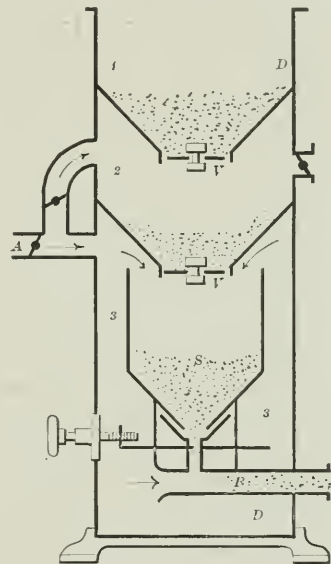


FIG. 455.—AIR-LOCK SAND-BLAST TANK.

The external cylinder, *D*, is divided into three compartments, two air-tight and the topmost a hopper open above. The sand, shovelled through a sieve in this last, falls through valves into compartment 2, thence through similar valves into the open-mouthed sand box, *S*, fixed in compartment 3, and from this through a funnel-mouthed pipe into the open end of the delivery pipe, *B*. The compressed air enters at *A*, fills compartment 3, inclusive of the space above the sand in the box *S*, and dries the sand as it falls from the latter along *B* to the blast pipe, a piece of plain chilled iron or steel tube from

$\frac{5}{16}$ to $\frac{7}{8}$ -inch bore, which is held in the hand at the further end of a length of flexible hose attached to the end of *B*. The sand in *S* being in equilibrium as regards pressure of air, falls freely by gravity; its volume is regulated by a screw sliding valve, the head of which is outside the drum. Compartment 2 is also filled with compressed air from a branch of the pipe *A*, but this is allowed to escape by the relief valve in order to open the valve in the hopper every time fresh sand is added, so that the issue of the sand blast is continuous and uninterrupted. The recent improvements and inventions of Mr. Matthewson, manager of the Tilghman Sand Blast Company, Sheffield, England, have given a new impetus to the use of the sand blast for a great variety of purposes. In these machines the best points have been retained, and there has been secured also the full efficiency of the blast, due to the pressure at which it is used, unreduced by the admixture of any dead air carrying the sand with it, at just the place where the maximum velocity is desired. This machine uses air at all pressures, but those about ten pounds to the square inch are found to be the most satisfactory. By immersing the whole sand supply in an atmosphere of air at the above pressure, contained in a tight reservoir, the advantages of a pure gravity feed are obtained, uncomplicated by any questions of difference in pressure inside of the jet tubes and without. Then, by the use of a flexible tube of considerable diameter, the sand and air, in a mixed current, are carried to a point where they are to be used. Here the flexible tube is connected with a hard chilled iron cone, terminating in a tube of small diameter. In traversing this latter portion of its course the mixed current of sand and air increases its velocity inversely as the square of the diameter of the tube, and is finally discharged from the end of the blast nozzle at the full velocity due to the pressure behind it. An air-lock arrangement for transferring new supplies of sand into the sand reservoir, while still under pressure, and valves for operating and graduating the air and sand supply, with a suitable com-

pressor for furnishing the supply of compressed air, complete the arrangement.

In metal it is used for the removal of the hard scale, so destructive to cutting tools, from castings and forgings. Among the applications are the removal of the scale from sheet iron and steel prior to enamelling, galvanizing, nickelling, tinning, etc.; the cleaning of tubes and brazed joints, largely used in bicycle work; sharpening the teeth of files; for granulating or frosting electroplate, gilding metal, gold- and silversmiths' work, and jewelry; the reduction to clean metal surfaces of larger works, ranging from steel forgings of safes to armor plates; on stone, slate, and granite, for incised carvings and inscriptions in intaglio or relief; for cleaning off the grime from stone, granite, and brick buildings, and, in contrast to this last, for the most delicate drawing for lithography.

Among other purposes it is employed for removing fur and deposits in tubes and tanks; for cleaning off accumulations of paint and dirt within iron ships; for roughening the surfaces of metal rollers; for decorating coat and other buttons; for granulating glass to give it a key for ornamental painting by hand; for piercing the apertures in glass ventilators; for marking cakes of glue and cement; for marking pottery and in the manufacture of ornamental tiles; for smooth-facing bricks to receive white glass or enamel; for refacing grindstones, emery, and corundum wheels; for granulating celluloid films for photography, and on wood to bring out the grain in relief, and latterly for blocks for printing.

For stone, marble, slate, and granite, the abrasives are sand, emery, and chilled iron sand, delivered at from 10 to 15 pounds pressure, usually from the compressed-air apparatus already described. The overlays are similar to those for glass; if for original designs, they are cut of thick porous paper saturated with the glue and dextrine, by which also they attach to the plain or polished stone; for work often repeated they are frequently iron stencil plates. The quick, yet gentle action of the process

annuls all risk of "plucking" or splaying the stone; but in some materials and marbles and in granite, which may be considered conglomerates, the harder are rather less cut away than the softer constituents; the sparkling granulation then produced is itself decorative, but, if required, it may subsequently be smoothed and polished.

Granulating designs with overlays and frosting on moderate-sized works in metal are generally conducted within a closed drum or box glazed on one or more sides to watch progress, and with holes in the sides of the box with elastic sleeves for the hands to hold the work in the vertical sand blast.

A beautiful translucent variety, known as chip or crystalline glazing glass, covered with gray filaments and fern and feathery markings on an ice-like ground—is also remarkable for the peculiarities of its manufacture. The surface, first uniformly frosted with the sand blast, is then covered with a coat of strong glue, and when this has set, the sheets are placed in horizontal racks in a room heated to 160°. In the course of ten or twelve hours, the hardening glue audibly cracks and springs off in patches, bringing away thin flakes of the glass with it. The fern-like markings are irregular portions of the original sand-blasted surface which remain on these flat conchoidal fractures.

This simple process was discovered by an accident, and put to use by Mr. Corsan in England. Beyond the curious fact that glue, under such conditions, will tear flakes from glass, the explanation appears to be that the hardening glue gradually blisters, and these blisters, as they detach, tear off more of the glass by their margins than toward their central portions, which latter leave the fern-like markings. By the employment of the ordinary overlays prior to frosting and gluing, the crystalline effect is sharply localized and confined to any portion of a design.

Lamp globes and spherical objects are plain or pattern-frosted all over their superficies in an ingenious manner. The

drum of the machine—about as high as its diameter—has a hinged cover, and moves round on a central vertical pivot. Diametrically within the drum is a spindle, or rather the two ends of a spindle, its central portion removed and replaced by corresponding rods, with spring means of holding, which carry the glass globes. The globe when in its place is exactly in the centre of the drum, and the tube of the sand blast, presented horizontally, points to the centre of the globe. During the frosting the spindle is continuously turned, and the drum itself moved round on its pivot through about a half-circle, both automatically; the central line of the spreading sand shower—its most active part—thus always points to the axis of the globe, which secures absolute uniformity in the texture of the frosting. Dry sand and air, at about one pound pressure, are used for ordinary work, and very fine sand, with steam at about 20 pounds pressure, for the best class of this work. The globes are replaced with expedition, and from 60 to 100 may be completed in an hour.

In ordinary lithography the design is drawn on the pure, smooth, polished stone in a greasy chalk or ink, and, although almost inappreciably, really stands just in relief; when printed from, the stone is kept constantly wet with water, which repels the ink—applied with a roller—from all parts of its surface, except the greasy lines of the drawing; upon these the water cannot stay, and they alone receive the ink and print.

In sand-blast lithography this is partly reversed. The whole surface of the stone is first impregnated with grease, so that, if then inked, it would print a uniform black; and this surface is then eaten away to a trifling depth with the sand

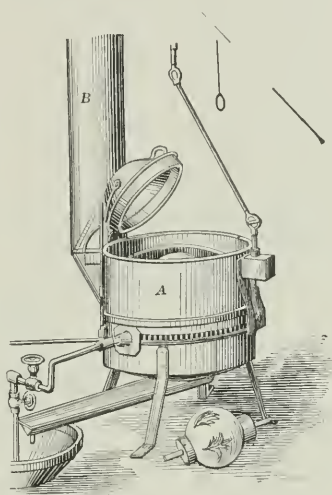


FIG. 456.—DRUM SAND BLAST.

blast, to entirely remove the grease from all portions that are not to print, that is, which are to give white; to granulate, or more or less destroy it upon those to give different tones of shading; and to leave it intact upon those that are to print black. All that remains of the original greased surface, therefore, alone prints; the stones being wetted, as usual, prior to inking for every impression.

Sand-blast engraving has been tried for steel-plate printing, and, although still in the experimental stage, it gives good promise of a future. The granulation from the fine emery powder gives the character of a mezzotint, but unlike an ordinary plate, upon which the rocking is generally uniform, so

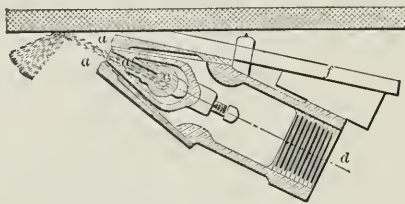


FIG. 457.—THE FILE SAND BLAST.

that it would print a solid block, and is then reduced in tones by scraping and bur-nishing to produce the drawing, the granulation of the sand blast may be localized and arrested on any portion

at any depth of tint; thus reducing the subsequent scraping to a minimum. In printing, the plates are treated just in the ordinary manner; the whole surface is inked, wiped clean of the ink, and finally polished with whiting on the palm of the hand.

Worn-down files are resharpened in the sand blast by being slowly drawn several times from tang to point between two converging streams of fine sand—sand worn so fine in grinding plate glass as to have become valueless for that purpose, and a waste product, is preferred—projected by compressed air at about 60 pounds pressure, which pass on from the file into a receptacle for reuse. The effect is rapid, and on both sides of a flat or on all four sides of a square file simultaneously, a fourteen-inch rough or bastard file being resharpened in two or three minutes; on second cut and smooth files the blast acts still more quickly, blasting away the curves until they again meet the upright sides of the teeth, and at but little less angle than before.

The file throughout the process is drawn across a piece of gun metal fixed between the sand blasts, and the equal hang of the teeth to this "feeling piece" tells the operator the resharpening is uniform from end to end.

The thorough work of the sand blast has been recently demonstrated in the cleaning of old paint and dirt from structural steel work for preparing it for repainting, the structure being the viaduct at One Hundred and Fifty-fifth Street, New York

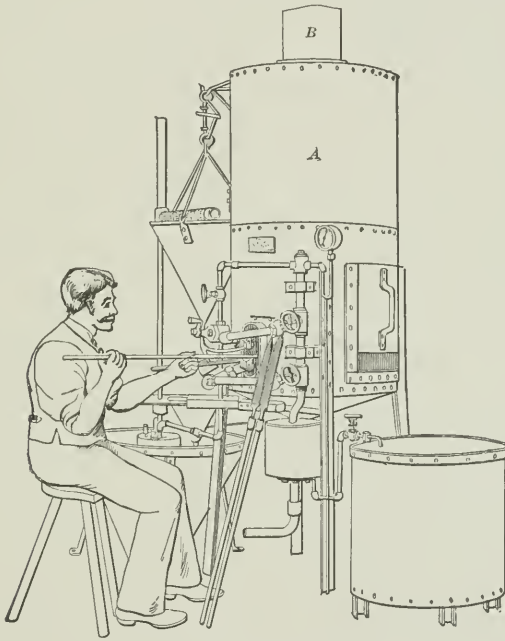


FIG. 458.—SHARPENING FILES.

City, which had been painted many times to prevent injury to the steel trestle-work by the smoke and gases of the Elevated Railway locomotives. Rusting had taken place under the many coatings of paint, and blistering and peeling had given the work an unsightly appearance with indication of damage to the structure. For this work compressed air was conveyed about 300 feet from a compressor to a receiver, and to the sand-mixing apparatus on a temporary flooring in the trusses of the viaduct.

A hose connects the sand-mixer and nozzle, which was held close to the surface to be cleaned. A section of the trusses was made perfectly clean in the early part of the day, and at once painted by the air-blast process, thus giving the paint a perfect contact with the metal and by this means obviating the formation of rust from loose scale.

For cleaning the walls and trimmings of buildings the sand blast has proved a perfect success. For removing the smoke and fire stains on the walls of buildings that have been burned and are found safe for rebuilding, the sand blast has been a saving clause in the expense of rebuilding, as was tested in cleaning the walls of Pardee Hall, Lafayette College, at Easton, Pa. The stone facing and trimmings of the New York Central & Hudson River Railway station in New York City have undergone a most satisfactory renewal by the sand-blast process.

The air blast finds one of its useful effects in sanding paint on car roofs and buildings wherever sanded paint is needed for special protection. The sand thus thrown with great force imbeds itself in the paint, and the air blast without the sand blows off the excess.

The air blast is also used for feeding coal dust and fine culm to boiler and other furnaces, and in the petroleum burner with its steam combination it contributes a most important condition in the combustion of liquid fuel.

Fig. 459 illustrates a petroleum burner, for a furnace, for a boiler, or other requirements. *A*, entrance of oil to central nozzle, which is regulated by a needle valve with screw spindle and wheel, *C*; *B*, entrance of compressed air to the annular nozzle, the force of which draws the oil and atomizes it for quick combustion.

The air blast is also used for elevating, drying, and aërating grain, for elevating coal culm, and discharging ashes.

Compressed air is also used for discharging the oil from tank cars to a higher level by sealing the manhole and forcing air above the oil.

The discharge of sand, soft material, and water from the foundation caissons of bridge piers by the direct action of compressed air has become a most important adjunct in caisson sinking, and was used in sinking the caissons of the Brooklyn and New York bridges to great advantage. A pipe, usually about four inches, is inserted in the roof of the caisson, extending up through the loading masonry and overboard to a scow. The lower end is extended down to a sump, with a quick-opening gate. The sump is used for a drain basin, into which sand, clay, and mud are thrown and ejected with great velocity by the air pressure in the caisson; the air lock being used for the passage of the men, tools, and material required for the sub-masonry.

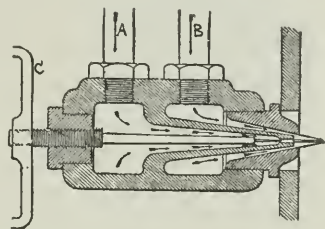


FIG. 459.—PETROLEUM BURNER.

THE AIR BLAST IN PAINTING.

The air blast for painting is comparatively a late innovation in the old and staid art of wielding the paint-brush by hand; but the times are progressive, and the use of compressed air in the arts keeps pace with its extending use in mechanics. Like all other progressive movements leading to new ways and means, this is also a labor-saving operation and is becoming an important and economical helper in the work of painting. For structural work, bridges, and the painting of railway cars, it is gaining a fast foothold for good and economical service. It is not only used for oil painting, but has proved a most efficient method of whitewashing and kalsomining walls and fences. Further, the finer points of the artist's conceptions have taken the air blast in hand for pictorial illustration. The atomizing of colored fluids in a spray from sharp lines to faint shadows is the outcome of the air-blast process, which has been applied to the production of picture work.

The simple hand compressed-air paint-pot is shown in Fig. 460. The thumb key is for regulating the air blast, and the valve wheel at the left side regulates the flow of the paint. The paint pipe starts from the bottom of the can and joins the air pipe and spray nozzle as shown in the cut.



FIG. 460.—HAND AIR PAINT-POT.

Fig. 461 represents a paint-spray nozzle as usually constructed. The inner or air nozzle, usually $\frac{1}{8}$ -inch opening, is made on the best lines for high air velocity and is fixed central to the larger opening in the inverted conical nosepiece, which is flattened to a thin opening, $\frac{1}{32}$ inch, to project the paint spray in a thin sheet. The paint is drawn in at the side inlet of the tee piece, and both air pressure and paint supply are regulated by valves, both pipes being under the same pressure from the paint tank of from 50 to 80 pounds per square inch.

In Fig. 462 is detailed the Mason painting machine, which consists of a steel paint tank strong enough for a working pressure of 100 pounds per square inch; a small hand air pump mounted upon the top of the tank, with suction and pressure pipes connected to the top of the tank in which are the three-way cocks *A* and *B*. To the tank connection at *F* is a pressure gauge and the air pipe and cock at *C*. *E* is the paint discharge pipe. The tank is charged from the mixing barrel by the siphon and cock *D*.

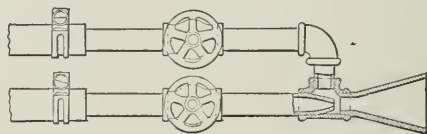


FIG. 461.—PAINT SPRAY NOZZLE.

The operation, then, is as follows: to charge the tank, the cock *D* is closed, the three-way cock *A* is turned to communicate the suction of the pump with the tank. The three-way cock *B* is turned to discharge the air at its side outlet with closure on the tank, the cock *C* being closed. The pump is then operated to exhaust the air from the tank, producing a degree

of vacuum measured by the gauge, which is both a vacuum and pressure gauge. The cock *D* is then opened, and the paint mixture is drawn into the tank in the desired quantity, or for continuous work about two-thirds full. Cock *D* is then closed: cock *A* is turned to shut off the tank connection and to draw air from the side inlet; cock *B* turned to connect with tank and shut off side exit. The pump can then be operated to charge the tank with the desired air pressure. For operating the spray, the paint hose is connected to the cock *E* at the bottom of the tank and the air pipe to the cock *C* at the top of the tank with the valves on the spray nozzle closed. The cocks *C* and *E* are then opened, which gives a balanced pressure in both pipes. When ready, open the air valve on the spray nozzle, and then the paint valve to meet the requirement of the spray. The ejector power in the nozzle draws the paint by overcoming the static pressure.

By varying the opening of the valves of the spray nozzle any density of the spray may be had from a thin cloud to a solid paint stream.

The air pump must be kept in operation to keep up the pressure according to the relative proportion of air and paint ejected. The nozzle should be moved slowly broadside over the work; a jerky motion scatters the paint. The same machine works equally well with whitewash or kalsomine.

In Fig. 463 we illustrate the Mason painting machine as operated by an electric motor belted and geared to a triplex air pump. By this arrangement the motor and pump can be placed in a convenient location for electrical connection and

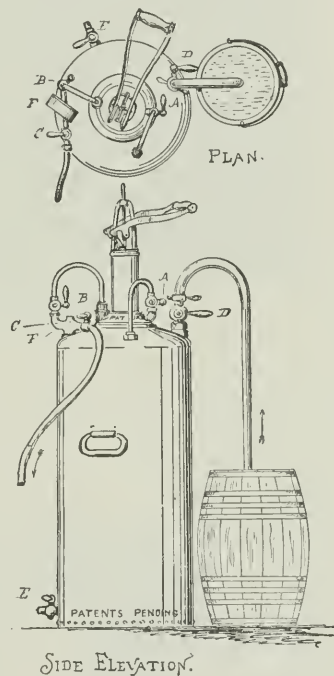


FIG. 462.—MASON PAINTING MACHINE.

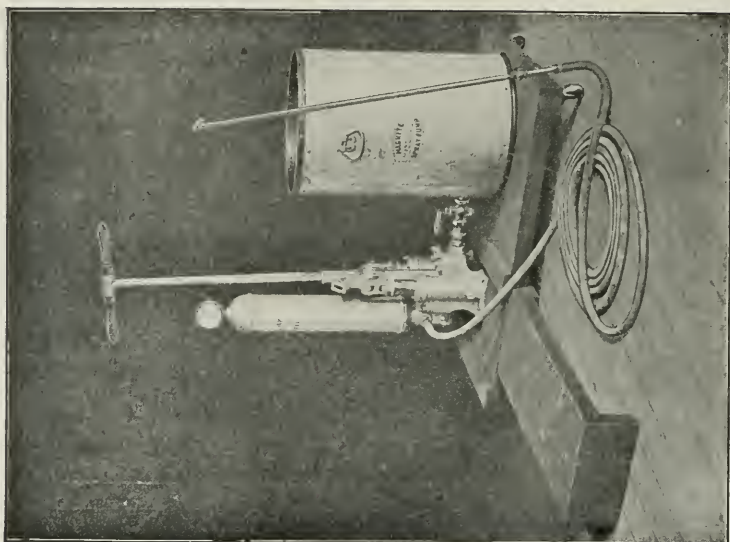


FIG. 464.—THE MAGNITE SPRAY PAINTING MACHINE.

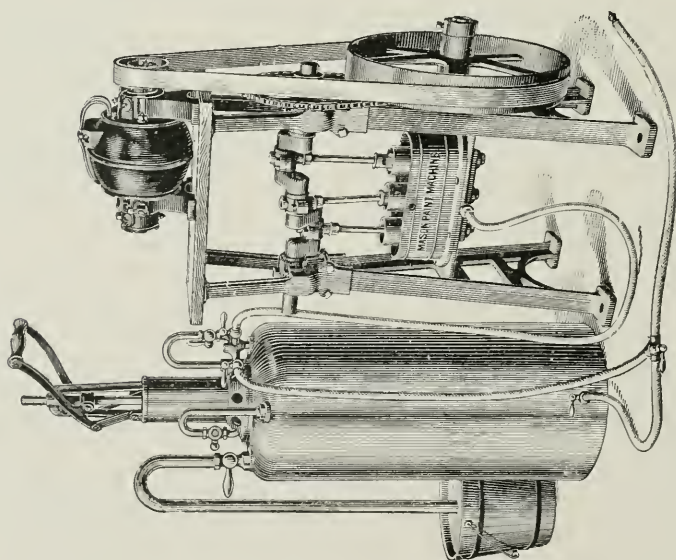


FIG. 463.—PAINT MACHINE WITH ELECTRIC AIR PUMP.

the hose extended to the tank, which should be in proximity to the work.

In Fig. 464 we illustrate the magnite spray painting machine made by J. A. and W. Bird & Co., Boston, Mass. It is

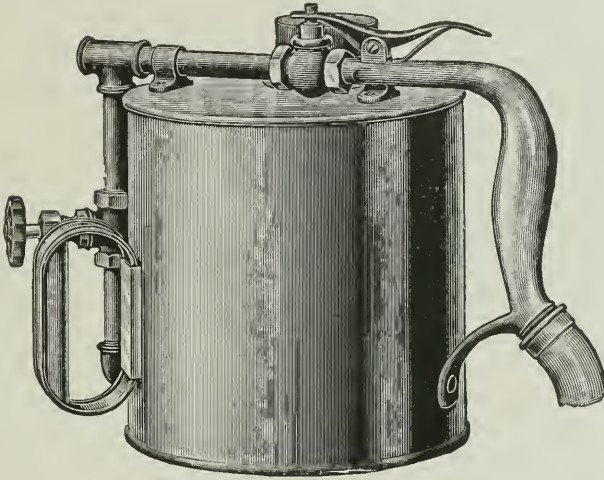


FIG. 465.—PNEUMATIC PAINT MACHINE.

Used as a hand painting-machine for car and structural iron painting. A record of fourteen minutes has been made with one of these machines in painting an ordinary box car. They are made by the Chicago Pneumatic Tool Company.

a portable machine, having all its parts mounted on a platform with casters. A two-cylinder air pump with single-acting trunk pistons operated by a hand lever, and with an air receiver and pressure gauge, constitute it a very simple and complete apparatus for spray painting with oil paints, kalsomine, and



FIG. 466.—CAR-DECK PAINTING.

other water paints, and for spraying antiseptics in hospitals, cellars, and on brewery walls. In fact, there seems to be no end to the uses that an atomizing machine can be utilized



FIG. 467.—CAR-SIDE PAINTING.

for. Paint machines are readily cleaned by pumping naphtha through them, discharging back into the tank. The spray painting of railway cars has now become an accomplished fact, and is in practice on a number of railways. We call attention to the fact that a perfectly atomized sprayed-on paint will almost instantaneously reach, cover up, and consequently protect a car's most complicated structural parts. It penetrates the rough beaded work—the open joints through shrinkage of sheathing—the crevices and other disfigurements usually met with when painting the new and repainting the old railway freight-car equipment.

There is evidence of the close observation made, from time to time, of sprayed freight cars and other large surface work done by the P. & L. E. R. R. Company, in the beginning, convincing us that the results from a standpoint of durability will not suffer on the score of fact that the paint was not applied with a brush.



FIG. 468.—TRUCK PAINTING.

COMPRESSED AIR FOR DUSTING AND CLEANING.

A novelty among the several hundred applications of compressed air for useful work and for time-saving in labor, is the air blast. It is only in recent years that the power of the air blast has been used for cleaning the dust from carpets, walls, ceilings, furniture, car seats, and, in fact, every place where dust can find a hiding-place. Not only this, but where disinfectants are needed the air blast is the most convenient vehicle for their distribution for best effect.

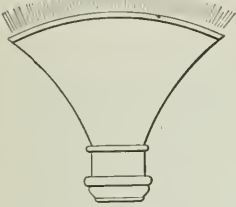


FIG. 469.—CURVED NOZZLE.

In this manner dwellings and public buildings may be quickly and cheaply renovated even to the draperies and bedding. Air can now be bottled at 3,000 pounds pressure per square inch, and thus made portable to be conveyed for use in any locality. Where an electric current can be utilized, an electric motor becomes a part of the house-cleaning kit for compressing the air. A gasoline-motor compressor on a light wagon becomes a complete portable outfit for house-cleaning, only requiring the extension of its air hose to the rooms or localities to be cleaned.

In Fig. 469 is illustrated the form of an air-spray nozzle for dusting with compressed air. This is a broad, thin nozzle from which a blast of compressed air penetrates fabrics, cleaning them of dust; a good cleaner of plain and carved woodwork. The open slit should vary in width from one-thirty-second to one-sixteenth of an inch, and in breadth from one to six or more inches, according to the kind of work it is to do.

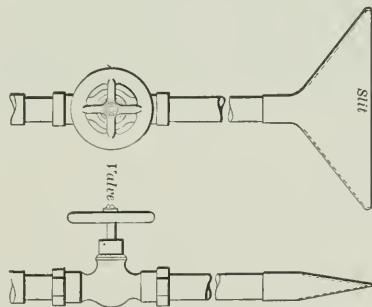


FIG. 470.—STRAIGHT NOZZLE.

The straight-edge nozzle (Fig. 470) is the most suitable for

flat work such as car-seat cushions and carpets that are dusted out-of-doors.

In Fig. 471 is illustrated a suction nozzle in which the compressed air is ejected against the point of the inverted cone,

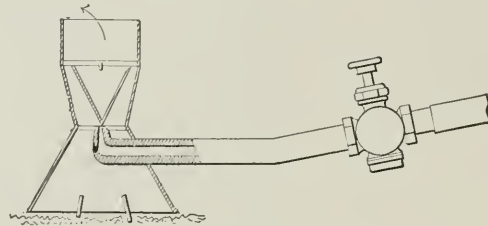


FIG. 471.—SUCTION NOZZLE.

which induces a strong current of air upward and from under the bottom of the inverted funnel, drawing the dust from the fabric and projecting it through a hose out of the windows; much used in car-seat cleaning.

For carpet-cleaning in dwellings where it is not convenient to use a hose for ejecting the dust through the windows, a filter hood or dust collector is used, which allows the air to pass through, retaining the dust on the inside. The filter hood is to be taken outside and cleaned when it becomes charged with dust.

The carpet-cleaner as illustrated is a box-shaped arrangement into which is injected a blast of air twelve inches long and one-hundredth of an inch wide. This blast strikes the carpet at an angle of 45° under a pressure of 75 pounds per square inch, removing all the dust from the carpet and depositing it in the receptacle. The cleaner is pushed over the carpet the same as an ordinary sweeper, and, besides removing all dust, the effect of the compressed air is to restore the carpet to its original color.

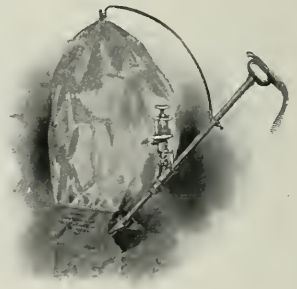


FIG. 472.—FILTER HOOD.

The cleaning of dwelling-houses and hospitals and the dis-

infection of walls, carpets, and furniture are coming largely into practice with the best results, and are now being conducted by the General Compressed-Air House-Cleaning Company, St. Louis, Mo.

In Figs. 472 and 474 is shown the disinfecting attachment on the pipe handle of the air-blast machine. A glass reservoir, somewhat like an automatic oil cup, is attached to the pipe



FIG. 473.—CARPET CLEANING WITH THE FILTER HOOD.

handle, with an air connection both above and below the fluid with a cock to regulate the flow of the disinfectant.

For spraying walls and ceilings the reservoir connection is inverted and a spray nozzle takes the place of the box.

In Figs. 475 and 476 is illustrated a machine for cleaning and removing dust from carpets and other similar fabrics by the air-blast process; it is in use in carpet-cleaning establishments.

Hitherto, when machinery has been used for this purpose, the system employed has merely been an amplification of the

crude method of hand-beating, sticks, chains, straps, or ropes being used. Carpets submitted to this beating or "hammering" process are frequently torn and otherwise damaged; holes are enlarged, and worn, tender places are made into holes. In the air process illustrated all chance of damage is eliminated, as



FIG. 474.—DISINFECTING ATTACHMENTS.

no form of beating whatever is resorted to, the cleansing being effected solely by the use of minute jets of compressed air driven at a pressure of 45 to 50 pounds per square inch entirely through the fabric. These carry along with them every particle of dust from the carpet without any damage whatever. The illustration (Fig. 475) represents an elevation of the pneumatic carpet-cleaning machine, and Fig. 476 an elevation at the driving end of the machine.

From these it will be seen that nearly the whole of the machine is enclosed in a hexagonal casing provided at each side with swing doors for the insertion and withdrawal of the carpets. Compressed air is conveyed from the main pipe by means of the two flexible branch pipes to the longitudinal feeder pipe running the entire length of the machine. This pipe is fitted at intervals of two inches with a number of nozzles, each having small holes at its nose, through which the compressed air escapes in minute jets

at great velocity, onto and through the carpet. This is carried slowly under the jets by the central wire roller, to which a

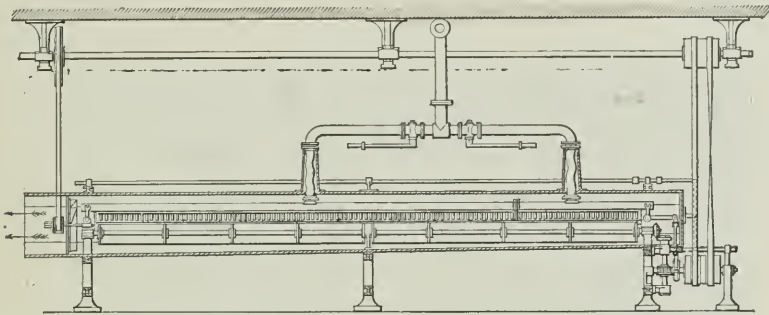


FIG. 475.—CARPET-CLEANING MACHINE.

rotary motion is given by the bevel wheels and driving pulleys shown. After the carpet has once been passed through the machine by the roller, if found desirable—as in the case of very thick carpets—it can be passed through a second time by reversing the action of the revolving roller. The feeder pipe carrying the nozzles rides at each end on trunnions, carried by an upright lever and shaft, to which an oscillating motion sidewise is given from the driving shaft by an eccentric and rod; the

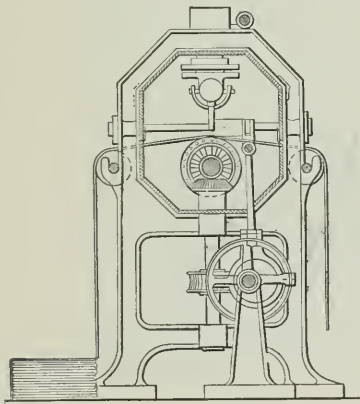


FIG. 476.—END VIEW.

object of this oscillation is to thoroughly distribute the air currents over the entire surface of the carpets passing under it. This pipe is further divided into two unequal sections, from either of which the compressed air can be shut off when carpets narrower than the full width of the machine are being cleaned. The whole of the dust removed from the carpets, by the action of the

compressed air thereon, is drawn away from the machine by an air propeller or exhaust fan at the left-hand side; the dust being delivered into a chimney, flue, or other suitable receptacle.

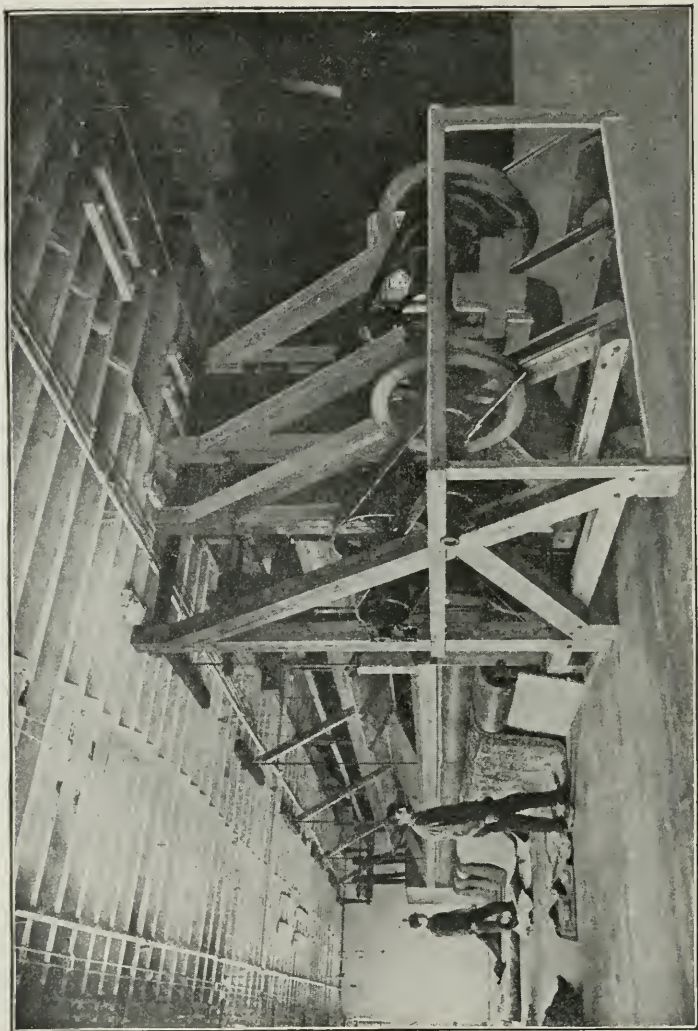


FIG. 477.—CARPET-CLEANING MACHINE OF THE AMERICAN PNEUMATIC CARPET-CLEANING COMPANY, 540 WEST 23D STREET, NEW YORK CITY.

By this method, carpets are cleaned so effectually that any amount of beating afterward fails to extract any dust, colors are revived, while the fabric sustains no injury whatever. Carpets of any description, cloth, and other like materials can be similarly cleaned by this process.

The American Pneumatic Carpet-Cleaning Company has plants located in New York City, Chicago, Boston, Philadelphia, Pittsburg, and Cincinnati.

Chapter XXIX.
PNEUMATIC WORK—Continued

PNEUMATIC WORK.

(Continued.)

COMPRESSED AIR IN THE BESSEMER CONVERTER AND THE BLAST FURNACE.

IN no other industry is the use of compressed air so important a factor as in the manufacture of iron and steel. The blast furnace stands first in estimation with its vast volumes of air at varying pressures up to 10 pounds or more per square inch, and extending in pressure up to 75 or 100 pounds in operating the Bessemer converter, and in the lifts and cranes necessary in the modern methods in steel manufacture.

The Bessemer converter and its adjuncts require the most precise and delicate handling of compressed air of any air power in the manufacturing arts. A slight mistake in handling the air valves, or in blowing the melted iron to the exact degree to convert it into steel, may involve large costs, if not disaster.

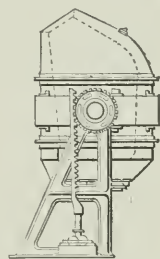


FIG. 478. — BESSEMER CONVERTER.

THE USE OF COMPRESSED AIR AT A BLAST-FURNACE PLANT.

When "A" Furnace of the Maryland Steel Company, Sparrow's Point, Md., was blown in for its second blast (November, 1895), a compressed-air plant was put in, and has been used with much success during the past years. Compressed air is used for the tap-hole drill, the tap-hole "gun," the transfer table at the scales, the turn-table on top of the furnace, and for lifting the rails of the turn-table in running off the empty cars.

The tap-hole drill is a Little Giant rock drill so mounted as to swing into place and drill out the tap-hole without any hard

manual labor. This arrangement is the device of Superintendent David Baker, and is described by him in *Trans. Amer. Inst. Min. Eng.* (vol. xxi.) The supporting crane has been much changed since that description was written, and now consists of a simple and light crane. The crane is fastened to one of the columns at the side of the tap-hole so that the drill can be swung back out of the way when not in use. The air-pipe is connected by swing joints and an expansion sleeve.

Formerly steam was used to run the drill, but it has several disadvantages which air has not. Great care had to be taken to prevent the condensed steam from dripping into the iron trough and perhaps causing a "boil." The escaping steam would make it hot for the men, and the clouds of vapor would often prevent them from watching the work well. A hose for the exhaust was necessary, and this made another part to care for, and it was sometimes burned. In cold weather there would be much condensing and loss of power. Compressed air does away with all these difficulties.

The tap-hole gun is S. W. Vaughen's patent device for shutting the tap-hole by power, thus saving much hard, hot work for the men, and doing away with the necessity of taking the blast off the furnace after each cast to shut the tap-hole.

The gun has a breech for loading, a compact valve, and a simple and adjustable mounting. It is made of cast iron and consists of two cylinders and a piston rod with a piston on each end. The air end of the gun is an ordinary air-cylinder operated by a hand-valve. The clay barrel is open at the nose end, and has a breech at the other end. The gun is suspended on a crane fastened to a column opposite the drill. The crane is similar to the drill crane, and the air-pipe has swing joints and a rubber-hose connection to allow freedom of motion.

The gun is loaded with about thirty-five clay balls before the cast, and when the iron is all out of the furnace the gun is swung around and clamped into place and the whole charge shot into the tap-hole at once. By reversing the valve

the piston is brought back; the breech is opened, the clay barrel loaded up again, and more clay shot into the hole till it is completely shut up.

Here the air has the same advantages over steam as in the drill. About 65 to 70 pounds air pressure is needed for the drill and gun. If at any time there is not enough pressure to run the drill well, a signal is given from the furnace to the pump-man, and he sets the escape valve of the receiver for higher pressure.

In order to have rapid handling of the ore, limestone, and coke, buggies are used, which have four wheels, run on tracks, and hold from 1,500 to 2,300 pounds of stock, at the scales; a transfer table is placed between the scales and the elevator, which is operated by compressed air taken from the blast main air-pipe at 10 to 12 pounds pressure.

COMPRESSED AIR IN A ROLLING-MILL.

Most of the more successful iron-working establishments now use "compressed air" a little—some a great deal; and among the foremost of the latter class is the Passaic Rolling-Mill Company at Paterson, N. J., not only because of its extensive use of compressed air, but particularly by reason of the variety of operations performed by it, several of which are of more than ordinary interest and originality.

First a row of jib cranes, each equipped with independent air hoist, used for loading the finished material on cars for shipment. The air cylinders for this work are about 6 inches diameter by 6 feet stroke, mounted on the mast, the air connection being made with a short piece of hose at the top of the crane.

One of the most interesting applications of compressed air, one in which work formerly required the services of thirteen men, is now done by four, and with less danger. By it the capacity of the rolls has been trebled. This apparatus is not

operated entirely by compressed air, steam and air being assigned to the work for which each is considered best suited. It consists of two transfer tables, one on each side of the main rolls of the rolling mill, the duty of one of which is to deliver the heated billet to the first roll, move into position to receive it from the second, move and deliver it to the third, and so on till the billet comes out a finished beam. Of course the process described applies to the table on one side of the rolls only, the one on the opposite side operating in the same way with it. This transfer table consists of a heavy four-wheeled carriage carrying a tilting platform or girder, the top of which consists of rollers operated in either direction by bevel gears and shaft. The carriage travels in the pit on rails parallel to the rolls in moving from one roll to the next, and the end of the tilting table next the rolls is raised and lowered to position for the upper and lower rolls by an 18-inch air cylinder located in a yoke. The cross-bend is connected at its centre to the piston of this air cylinder and moves the tilting platform by means of the side rods fastened to its ends. The action of this cylinder is controlled by a special valve, operated from the engineer's platform. One engineer and a roll-tender are all that are required for the apparatus, and the same number for the other table on the opposite side.

After the beam leaves the rolls it passes to the hot saw, where it is trimmed and cut to length. The rollers that carry the beam to the saw receive it from the rollers on the transfer table, without any handling or even a pause in its motion, so that a few seconds after it has received its last squeeze in the rolls it is being cut by the saw. This saw is fed through the beam by a compressed-air cylinder, which is 12 inches diameter by 20 inches stroke; the elastic yet persistent nature of the feed given the saw by compressed air is found much better than any other method.

Compressed air performs the next operation on the beam, which is to remove it from the rollers (making room for the

next) and set it on edge to cool. When the beam lies on the rollers after being cut to length the fingers are in a horizontal position under it between the rollers, and an air cylinder, 15 x 26 inches, located under the rollers, pulls the fingers to a vertical position, bringing the beam with it, at the same time carrying it sideways far enough to clear the rollers.

The rest of the work done by air in these works is being done in many places elsewhere, and is consequently of but passing interest. There is a busy corner in the bridge shop—a group of three riveters, two reamers, a chipping tool and hoist, all being operated by compressed air. The total pneumatic equipment of the works, outside of the special apparatus described, consists of about 40 cylinder hoists, 12 riveters, 5 drills and reamers, and 2 chipping tools. There is also a very interesting device for charging the heating furnace by compressed air.

COMPRESSED AIR FOR BLASTING COAL.

In endeavoring to dispense with the use of gunpowder and other asphyxiating explosives in the deep drifts of coal mines, a series of experiments were made in the collieries at Wigan and Denton, England, a number of years since, in which air was compressed to 946 atmospheres over 14,000 pounds per square inch, and conveyed in strong wrought-iron tubes to a cast-iron cartridge placed in a drill hole and tamped like a powder cartridge. The breaking strain of the cast-iron cartridges by comparative tests was first ascertained to obtain the proper size and thickness, that they might burst at or near some assigned pressure, say 10,000 pounds per square inch. Cored castings could not be used, or failed from the drifting of the core, causing weakness on one side, so as to vitiate many of the experiments. A size of drilled and turned cartridges was adopted, 12 inches long, $3\frac{1}{16}$ inches diameter, with walls $\frac{9}{16}$ inch thick, having a bore $1\frac{1}{16}$ inches diameter. This was found to burst at 9,500 pounds per square inch pressure. These air cartridges

were pushed into close-fitting bores in the undercut coal wall with a small pipe attached and tamped the same as with a gunpowder cartridge; the small air pipe was laid to a safe distance to a receiver charged at a much higher pressure, when on opening a valve the compressed air rushed to the cartridge and an explosion occurred much in effect like other explosives, and throwing down a wall face of from 5 to 6 tons at each blast. The air compressor placed at the power station readily compressed the air to the required pressure, which was transmitted to strong receivers near the working heads, where the operation of charging a receiver and a cartridge was readily done by the high-pressure valves at the receiver. In this manner the miners could carry on the work constantly without having to retire from the influence of deleterious gases, and had only to momentarily shield themselves from flying coal. The ventilating and cooling properties of air thus used cannot be too highly praised as one of the safeguards in the dangerous work of mining coal in the deep and gas-saturated workings of the bituminous coal belts.

Although the expense of blasting by compressed air was found somewhat greater than by the use of powder or dynamite, this system was proved feasible, but was not continued. It is assumed that compressed air yet stands foremost as a substitute for the dangerous explosives heretofore used, by the increasing depths at which safety is a paramount requirement.

THE AIR-LOCK SYSTEM IN CAISSON SINKING.

One of the latest improvements in the use of compressed air in sinking the foundations for buildings is the air lock, of which the outside feature is illustrated in Fig. 479. It consists of a large steel case or chamber containing the air-lock mechanism; a neck extending down a few feet and fixed to the top of the wooden caisson by a flange; a platform at the top as a footing for the men operating the caisson valves, and the hoisting of the

excavated material. This system enables an ordinary bucket, or even a barrel of cement, to be passed in and out of the caisson without detaching it from the hoisting-rope leading to the derrick. The lock has a simple lower door hinged on a shaft, which shaft extends to the outside of the lock through a stuffing box. On the outside is a counter weight lever and counter-weight, to balance the door and afford means of operating from the outside. Above the lower door is a cylindrical section, called the bucket chamber, large enough to contain the bucket. The opening above the bucket chamber, instead of being closed by a single door, is closed by two doors working to and from the centre. When these doors are shut they completely close the opening, and form a tight joint with each other, with the exception of a small opening at the centre. In this small opening at the centre fits a stuffing-box of simple design, through which the hoist-rope passes. The two doors then close around the rope contained in the stuffing-box and completely prevent the escape of air through the opening, while permitting the rope to pass freely. As soon as the bucket is filled in the working chamber an electric bell rings above, and the engineer at the derrick hoists the bucket into the bucket

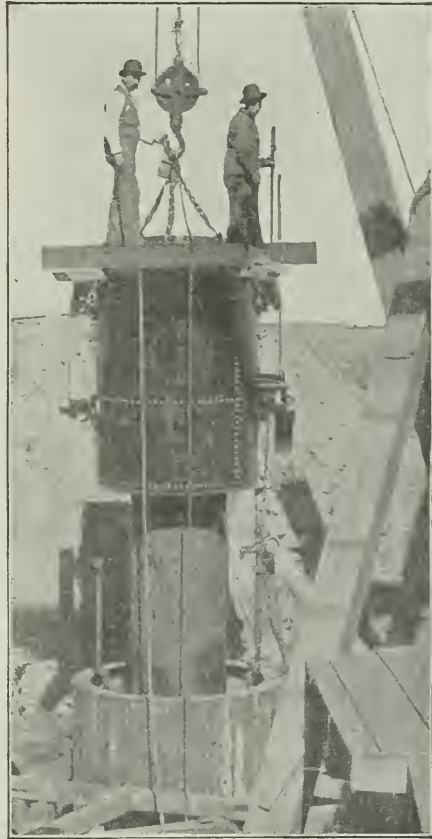


FIG. 479.—THE AIR LOCK.

chamber. The two doors then close around the rope contained in the stuffing-box and completely prevent the escape of air through the opening, while permitting the rope to pass freely. As soon as the bucket is filled in the working chamber an electric bell rings above, and the engineer at the derrick hoists the bucket into the bucket

chamber. The lower door is then closed, a valve is opened permitting the air in the lock to escape, the upper doors are then opened, and the bucket is hoisted out, the stuffing-box remaining on the rope just above the bucket. In returning, the operations are reversed.

The caisson is an excavating machine, as well as a foundation, and must be considered in that light.

The side elevation (Fig. 480) shows the air lock at the top, with the levers L L' and their counter-weights W W' , below which is the elevator or air shaft, with the ladder, as shown, and at the extreme lower part is the air chamber. The openings M and N are respectively for the air pipe and the whistle connection, as shown in the cut Fig. 480. The illustration Fig. 481 gives the details of the internal arrangement.

Referring to Fig. 481, the upper swinging gates, A and A' , turn about the centre, O , being counterweighted by V and V' . These are worked by the handle L , both gates swinging on the centres D and H .

When the upper gates have been moved to the open position, so as to come at rest on the lugs B and B' , the buckets can be moved in or out of the air chamber. The meeting edges of these, as well as the lower gates, are packed with rubber tongues, so as to make air-tight closures. The lower swinging gates

are worked in the same manner, being opened and closed by the lever L' , and counterweighted by W' (Fig. 480).

The successive operations are as follows: The bucket is lowered into the air lock, the upper gates being open and the

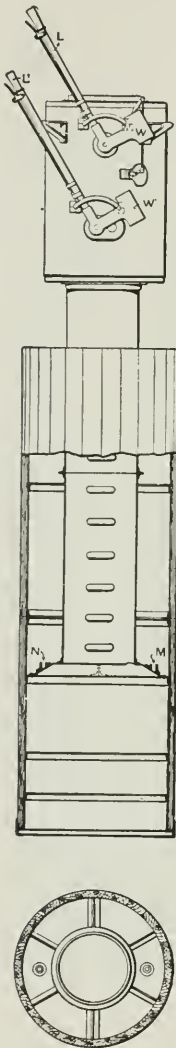


FIG. 480.—SIDE VIEW.

lower ones closed. The upper ones are then closed and air is admitted from the air shaft until the pressure equals the pressure in the air chamber. The lower gates are then opened and the bucket descends into the shaft and finally into the caisson chamber.

There is a three-way valve, which serves three purposes: First, it permits air to escape from the air lock; second, it equalizes the pressures in the air chamber and the air lock, and, third, it prevents the escape of air from either. It is regulated by means of contact wheels, which in turn are moved by connecting with the handle *L* by means of a rod not shown in the figures. When the upper gates are closed the motion of the lever simultaneously closes the air exhaust from the air lock and makes connection with the air chamber below, thus equalizing the pressure in the two chambers. A thumb-latch locks these doors in both the open and in the closed position. The arrangement of the lower swinging gates prevents their movement until the pressures in the upper and lower chambers have been equalized.

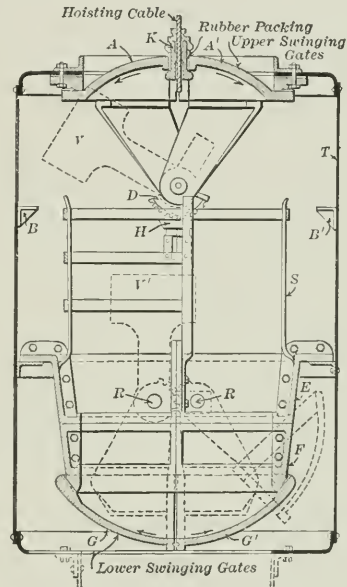


FIG. 481.—AIR-LOCK CHAMBER

Chapter XXX.

THE PNEUMATIC SYSTEM OF TUBE TRANSMISSION

THE PNEUMATIC SYSTEM OF TUBE TRANSMISSION.

THE earliest suggestion and experiment in the work of transmission in tubes was made by Dr. Papin in the seventeenth century, since which its usefulness lay dormant through the centuries until 1853, when the first successful pneumatic-tube system was put in operation in London, England, with a $1\frac{1}{2}$ -inch tube 650 feet long. It was operated by a vacuum and again extended in 1858 with $2\frac{1}{2}$ -inch tubes. From this on, the system has grown rapidly, and London has 34 miles of despatch tubes with 42 stations; the transmission power being by both compression and exhaustion. It has also extended its usefulness in the large cities of England and on the Continent. In Berlin, Germany, the transmission of telegraph messages by pneumatic tubes commenced in 1865. There is quite an interesting history of the experiments in transmission of passengers and goods by this system, covering many years of trial, but, as it has not proved successful, we pass it by. Its most successful score is in the store cash system, the telegraph despatch, and the later postal-transfer system.

Its first introduction on the larger scale was made in Philadelphia in 1893. A six-inch main was laid to connect the main post-office with the Chestnut Street branch, a distance of nearly a mile.

On account of the large size of the pipes compared to those used in the European system, the capacity of this plant was much greater. The area of the tubes was increased many times, and of course the carriers were correspondingly larger. The speed of the Philadelphia system was, moreover, doubled, and it had improved appliances for receiving and transmitting.

This plant was opened in 1893 and has been operated successfully ever since.

The air current flows continuously from the main post-office to the Bourse through one tube and returns to the main post-office through the other, thus forming a loop with the return end connected to the suction pipe of the compressor at the post-office. There is an opening in the tube to the atmosphere near where it is connected to the compressor, so that the entire circuit contains air at a pressure above the atmosphere. It is a pressure system rather than a vacuum system, as these terms are commonly understood.

Carriers occupy sixty seconds in transit from the post-office to the Bourse, and fifty-five seconds for the return trip. The carrier is only 18 inches long; but each carrier has a capacity of 200 letters, and they can be despatched at six-second intervals, making the tube capacity 240,000 letters per hour, including both directions. The actual speed in practice is about 52 feet per second, in the Philadelphia service, and in the first four years it was in use it is estimated that more than 35,000,000 letters were despatched through these tubes, with but one serious interruption due to an obstruction in the tubes.

It was determined for the New York system to make the tubes of larger capacity than those used in Philadelphia, and to maintain a working speed of thirty miles an hour under a headway of twelve seconds. The line to the Produce Exchange is nearly 4,000 feet long and consists of two tubes, side by side, 8 inches in diameter, and about 5 feet below the surface. One is used for outgoing and the other for incoming mail, they being connected at the sub-station by a loop. A powerful compressor forces the air into the outgoing tube at a pressure of 7 pounds to the square inch. On account of its elasticity, it flows through the pipe with an increasing velocity, but by the time it reaches the sub-station the pressure has fallen just one-half. From here the current returns by the second or return tube, and as it enters the receiving tank its pressure is equal to that of the

atmosphere. This tank is joined to the suction pipe of the compressor, and as the two lines are connected by a loop at the other end, there is a continual circulation of air throughout. The pipes are of cast iron with a very smooth interior finish. All bends are of at least 8-feet radius and made of seamless brass with a diameter of not less than $8\frac{3}{4}$ inches on the inside.

The current is continuous from the starting of the compressors in the morning until they stop at night, so it was necessary to have some means by which the carriers could be inserted and removed from the line without interfering with the flow of air. This is done by means of a transmitter and receiver, one at

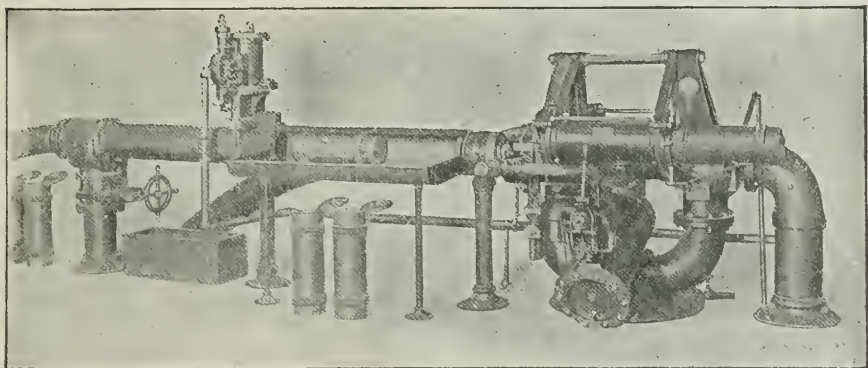


FIG. 482.—SENDING APPARATUS AND RECEIVER, NEW YORK POST-OFFICE.

each station. The former consists of a piece of 8-inch pipe, long enough to enclose the carrier. It is hung on a shaft, overhead, so that it can be swung out from the main line to receive the carrier and then moved back into position where the current forces the latter into the main tube. The ends are smoothed off square so that no air can escape at the joints. When this section is swung out of line two projecting plates move across the ends of the opening and shut off the air, the current meanwhile going around by means of a connection. When the transmitter is not in use the movable section is drawn over to the loading tray and the air goes through the U-shaped by-pass. When a carrier is to be sent it is placed in the tray and pushed

into the transmitter; then, by pulling a lever, the latter is swung into position and the carrier is forced out. An automatic time-lock prevents them being sent with less than twelve seconds headway, thus insuring a proper distance between them in the tube. When the carriers arrive at the sub-station the pressure of the air is $3\frac{1}{2}$ pounds to the square inch, so the tube cannot be opened to remove them. They also have a velocity of about thirty miles an hour, and some means had to be provided for gradually checking their speed.

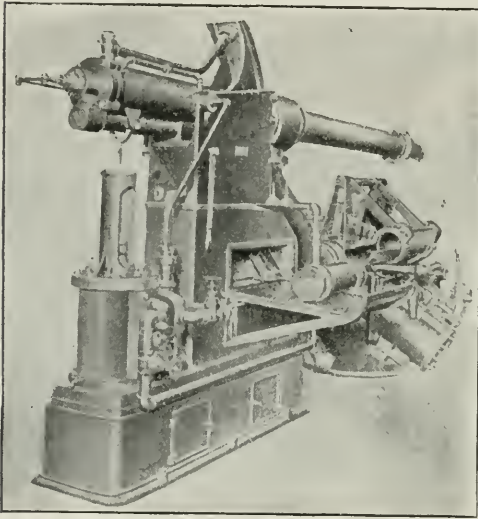


FIG. 483. —SENDING APPARATUS AND CLOSED RECEIVER AT A STATION.

These two things are accomplished by means of a closed receiver, which consists of an 8-inch cylinder 4 feet in length. In its normal position it forms a continuation of the tube by which the carrier arrives, and on entering the receiver it compresses the air in front and is stopped without any shock. There are

a number of openings in the pipe just in front of the receiver connected with the other or returning line by which the current continues back to the main station. The compressed air in the receiver opens a small valve and thus keeps the carrier from being thrown back into the main tube. The receiver is automatically discharged in three or four seconds by a piston, which tilts it to an angle of 40° . The carrier slides out onto an inclined platform which is kept in position by a counter-weight. The weight of the carrier, however, overbalances this and causes it to drop to a horizontal position, and the carrier is thrown out on to a table in front of the operator. This piston

is worked by compressed air supplied from the receiver. Above the front end of the receiving chamber is a plate, arranged so that it comes down and closes the end of the main tube when the receiver is tilted to be discharged.

The transmitters at both ends of the line are the same, but the receiver at the main office is different from the one at the sub-station. At this end it consists of a section of the end of the tube closed at the rear by a gate. The air, now expanded

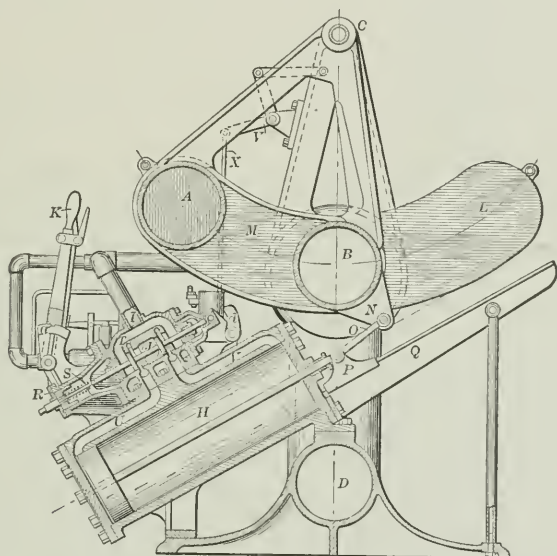


FIG. 484.—SECTION OF SENDING APPARATUS.

to the same pressure as the atmosphere, passes from the tube through openings, four feet in front of the receiver gate, down to the tank in the basement. The momentum of the carrier is checked in compressing the air in the chamber after it has passed these openings. Part of this compressed air operates a piston which opens the gate mentioned above, then the small pressure of air forces the carrier out on to the receiving table. If there is not sufficient pressure to expel it, the openings can be partly closed by means of a valve. As it passes out, it hits a small finger which causes the gate to be closed.

Intermediate stations are usually supplied with cut-out

switches, so that carriers can be sent directly past the station without entering it. These switches are moved by air pressure, controlled electrically from the nearest station (see Fig. 485).

There is no part of this system that has been the object of more thought and study than the carrier that contains the mail or other material to be transported. It is made of a seamless steel tube $23\frac{1}{2}$ inches long, closed at the front end by a sheet metal head and buffer, and closed at the rear end by a hinged cover provided with a lock (see Fig. 486). The right-hand carrier is of the New York system.

The body of the carrier is about an inch smaller than the tube through which it travels, the space between the body of

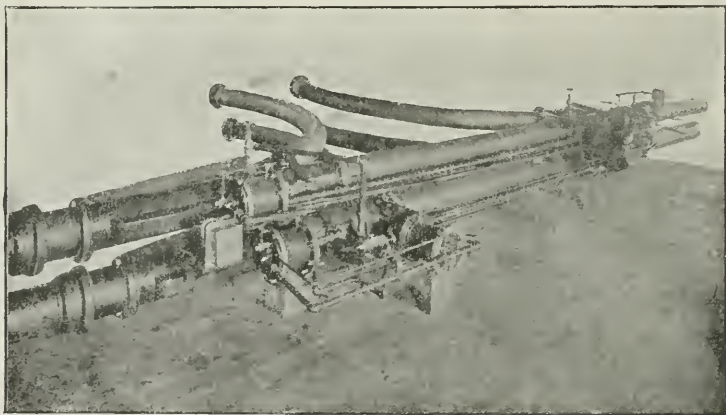


FIG. 485.—CUT-OUT SWITCHES FROM MAIN LINE.

the carrier and the surface of the tube being filled by two fibrous rings that serve not only to prevent the escape of air past the carrier, but as wearing surfaces to slide on the lower side of the tube. These bearing rings are made of cotton fibre, and they will endure until the carrier has travelled about 5,000 miles, when they become worn so small that they have to be replaced by new ones. A carrier weighs $13\frac{3}{4}$ pounds and will contain 600 ordinary letters.

In Fig. 486 is represented the comparative sizes of the carriers used in the progress and expansion of the pneumatic

transmission system. No. 1 to the left is the carrier used in the Berlin system; No. 2, the largest carrier used in the London system; No. 3, a six-inch carrier of the Philadelphia system; No. 4, an eight-inch carrier of the New York and Boston systems. No. 2 is also the comparative size of the New York telegraph despatch system.

LOCATION OF OBSTRUCTIONS BY LODGMENT OF A CARRIER.

Considerable apprehension arose from the accidental lodgment of a carrier in the Philadelphia tube, and also later in the New York and Brooklyn post-office line.

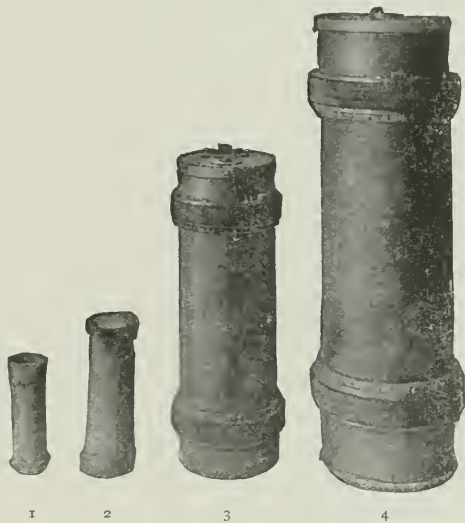


FIG. 486.—THE CARRIERS.

The plan was to disconnect the terminal apparatus at one of the stations, fire a pistol into the tube, and note the time that elapsed between the discharge of the pistol and the return of the sound as an echo reflected back from the obstructing carrier; then, knowing the velocity of sound, a simple calculation would give the distance from the station to the carrier.

A chronograph improvised for registering the time consisted in part of a metal cylinder or drum 10 inches in diameter, which could be revolved by a hand crank and which would move endwise very slowly when in rotation. The polished metal surface was coated with smoke, and therefore a motionless pin-point, in contact with the drum, would trace a fine spiral line thereon. The point was not motionless, though. It was attached by a horsehair and sealing-wax to one prong of a tuning-fork giving the musical note C, and therefore vibrating 512 times per second. Consequently 512 waves per second were imparted to the

trace; and these were large enough to admit of division into quarters. Another disturbance of the point was caused electrically by a pendulum of a clock beating half-seconds. Each beat made a short, sharp projection sideways on the wavy line. Hence, the complete half-seconds could be counted by these marks, while the time interval remaining after the last pendulum beat could be ascertained from the tuning-fork waves.

Finally, provision was made for automatically recording on the cylinder the instant of the original shot and also of the arrival of the echo. A vibrating diaphragm close to the drum bore another stylus or sharp point, and this diaphragm was so sensitive that, when struck by sound, it would move enough to make a scratch on the sooty surface.

Five trials were made with this apparatus, and the mean of the observations gave 2.793 seconds as the time required for the sound to travel both ways. A velocity of 1,093 feet was assumed for a temperature of 32° , and a correction of 1.12 feet per second for each degree above that standard was applied. The observed temperature down in the ground was 39° . The computed velocity was 1,101 feet, and the estimated distance, counting both ways, was therefore 3,075 feet. Dividing by two, the explorers made the actual distance of the box 1,537 feet from the open end of the tube. This was more than a quarter of a mile off. When workmen dug down at the designated spot, several blocks away, they found the box within a foot or two of the place. A break had occurred in the pipe about twenty feet further away, but the obstruction was found exactly where calculation located it.

THE ENGLISH TUBE SYSTEM.

Some computations have been made by English experts on the power required to operate a pneumatic-tube system of $2\frac{1}{4}$ and 3-inch tubes which is applicable to the larger tubes in the ratio of their comparative areas.

"The pneumatic tubes used in Great Britain are made of

lead, and when laid beneath the streets they are enclosed in iron pipes for protection. The tubes vary in length from two miles downward, the average length being about three-fourths of a mile. The diameter of the longer and more important tubes is 3 inches, and that of the shorter and less important tubes $2\frac{1}{4}$ inches. The carriers within which the messages are sent through the tubes are made of gutta-percha tubing, covered with felt, and have a head of several pieces of felt which accurately fits the tube. The carriers used with the 3-inch tubes weigh about 7 ounces, and will contain about thirty-six messages; those used with the $2\frac{1}{4}$ -inch tubes weigh about $2\frac{3}{4}$ ounces, and will contain about twelve messages.

"Each of the tubes is provided with a simple electrical contrivance by which the departure from and the arrival at each station of the carriers is signalled.

"The power by which these tubes are worked is derived from steam engines located at the central office. These engines work air pumps which either take air from the atmosphere and compress it to a smaller volume and then discharge it into the pressure main, whence it is admitted by means of taps into the different tubes when carriers are despatched to an out-station—or the pumps take air from the vacuum main, compress it to the atmospheric pressure, and then discharge it into the atmosphere; the air in the vacuum main is, of course, being continually renewed by the air which flows from the atmosphere through the tubes into the vacuum mains during the transit of the carriers from the out-stations.

"The velocity with which the carriers travel is usually between one-third and one-half a mile per minute. The approximate time of transit in minutes through a tube of L miles = $2.7 L^{\frac{3}{4}}$ with the $2\frac{1}{4}$ -inch tube, and $2.1 L^{\frac{3}{4}}$ with the 3-inch tube.

"The energy expended in driving a carrier from the central office to an out-station is equal to the volume of compressed air which flows into the tube during the transit multiplied by the work required to produce a unit volume of compressed air.

"The volume of compressed air which flows into the tube during transit is equal to about six-sevenths of the tube's cubical capacity. The capacities of the $2\frac{1}{4}$ and 3-inch tubes are 146 and 251 cubic feet per mile respectively, so that the volumes of compressed air used in driving a carrier through a mile of each tube are 125 and 200 cubic feet respectively.

"The work required to produce a cubic foot of compressed air at a pressure p_1 from a pressure p_0 lies between the isothermal value

$$0.01005 \, p_1 \log. \frac{p_1}{p_0} \text{ horse-power minutes,} \quad (1)$$

and the adiabatical value

$$0.01505 \, p_1 \left\{ \left(\frac{p_1}{p_0} \right)^{.29} - 1 \right\} \text{ horse-power minutes.} \quad (2)$$

So that to produce a cubic foot of compressed air at a pressure of 12 pounds to the square inch above the atmospheric pressure would require between 0.0695 and 0.0755 net horse-power minute, or say about 0.085 gross horse-power minute; and, therefore, the energy expended in driving a carrier through a mile of the $2\frac{1}{4}$ and 3-inch tubes would be 10.6 and 17 horse-power minutes respectively.

"When a carrier is despatched from an out-station to the central office, the air in the tube first expands into the vacuum main and thence into the pumps, where it is compressed to the atmospheric pressure and then discharged into the atmosphere. By the aid of formulæ 1 and 2, it is found that the gross amount of work of 0.065 horse-power minute is required to pump a cubic foot of air into the atmosphere from a vacuum main at a pressure of 8 pounds per square inch below the atmospheric pressure. If the tube has been at rest immediately before the carrier is despatched to the central office, the volume of air which will be pumped into the atmosphere from the vacuum mains will be equal to the cubical capacity of the tube; and, therefore, the energy expended in the transmission of the carrier would be 8 and 13 horse-power minutes with $2\frac{1}{4}$ and 3-inch

tubes respectively. If, however, the tube had immediately previously been used to receive a carrier from an out-station, there would be a partial vacuum in the tube, and, therefore, the expenditure of energy would be less, say $6\frac{1}{2}$ and $10\frac{1}{2}$ horse-power minutes respectively. But if, on the other hand, the tube had just previously been used to despatch a carrier to an out-station, it would be partially filled with compressed air; and the amount of work which the pumps would have to perform would be greater, and the amount of energy expended during the transit of the carrier would be about 12 and 19 horse-power minutes with the $2\frac{1}{4}$ and 3-inch tubes respectively.

"These amounts of energy would be expended in several different forms. First, work would be performed in pushing back the atmosphere at that end of the tube at which the pressure was lowest; secondly, energy would be expended in generating mechanical vibrations of the tube; and, thirdly, in overcoming the friction of the carrier within the tube. The first of these quantities is much the greatest, and is equal to about three-fourths the net work of the engine in pressure working, or about two-thirds the net work of the engine in vacuum working.

"The energy expended in overcoming the friction of the carrier may be approximately calculated from the formula $\frac{W L}{150}$ horse-power minutes, where W is the weight of the carrier in ounces and L length of tube in miles.

"Thus, with the $2\frac{1}{4}$ -inch tube, the energy expended in overcoming the friction of the carrier through a mile of tube would be about $\frac{1}{50}$ horse-power minute, or with the 3-inch tube about $\frac{1}{20}$ horse-power minute. So that the energy expended in overcoming the friction of the carrier itself would be only $\frac{1}{200}$ to $\frac{1}{600}$ of that expended in expelling the air from the tube."

The mail-tube industry has now developed so fast in this country that even 8-inch tubes, with cartridges carrying six hundred letters, are in successful operation in our big cities.

The longest circuit ever built in the world is in the main line recently laid in New York City, extending from the terminal post-office, a distance of three and one-half miles. This is an

8-inch tube circuit. The cartridges travel at tremendous speed, the time of transit consumed in either direction being only seven minutes. Another big circuit has been laid across the Brooklyn Bridge, so that you may have the pleasure of knowing that while you are speeding over the bridge in the cars, your mail may be making better time ahead of you, shooting away in the cartridge inside the big tube like an 8-inch projectile.

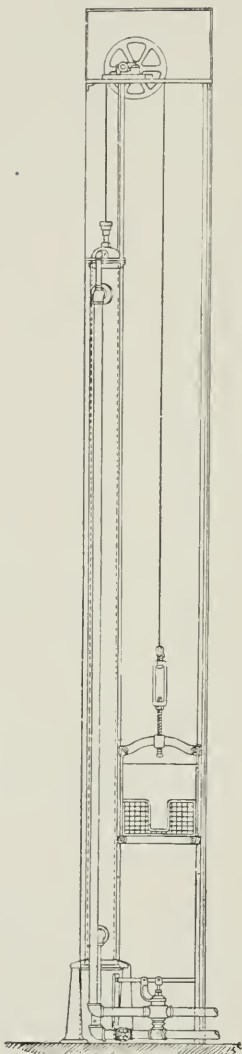


FIG. 487 —PARCEL LIFT.

COMPRESSED AIR IN STORE AND OFFICE SERVICE.

The pneumatic lift is one of the modern conveniences for the quick transmission of packages and light goods—in fact, a perfect compressed-air dumb-waiter service for our high buildings.

There are five air lifts in *The World* building, one of which runs up through the entire building, by which an immense business is transacted in transmitting copy and orders.

As will be seen in Fig. 487, a cylinder is employed which is equal in length to the range of motion of the car. On account of its length it is small in size, and can be placed in the elevator well. The suspender rope of the car passes directly into the cylinder, and is attached to the piston. The rigid piston is thus avoided, and therefore no doubling blocks or multiplying gear are required. The

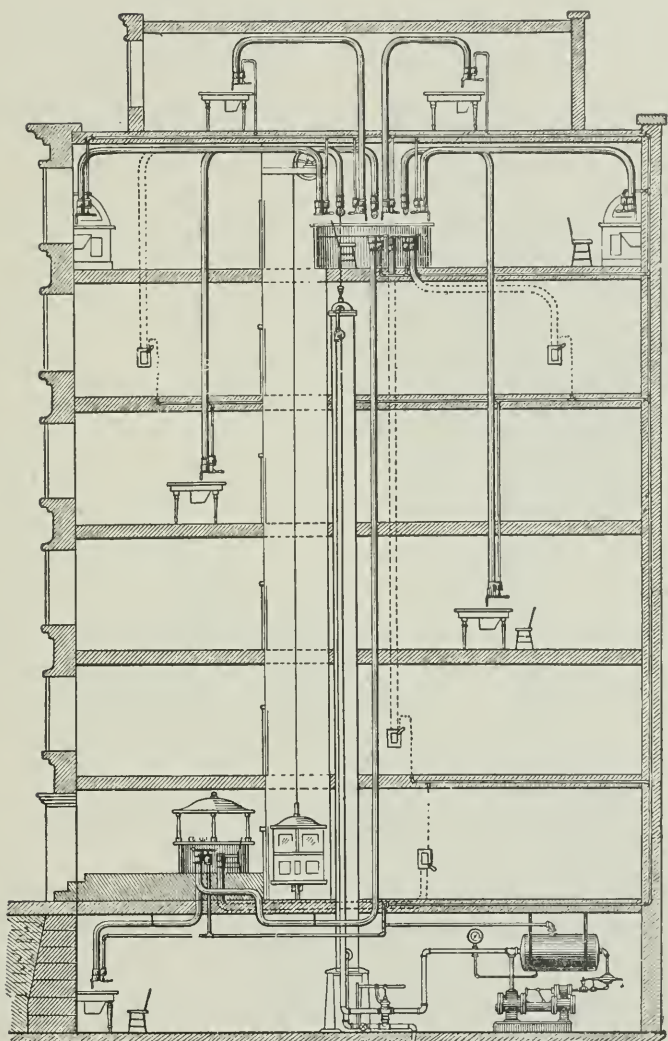


FIG. 488.—PNEUMATIC ELEVATOR AND TUBE TRANSMISSION.

For stores and office buildings. System of the Miles Pneumatic Tube Company,
1223 Broadway, New York City.

piston lifts the car by a force of compressed air let into the cylinder by a valve. The compressed air is supplied from a pressure tank, automatically regulated, precisely as it is for the operation of despatch tubes. Hence a system of tubes and light elevators can be operated from the same pressure tank.

The pneumatic elevator and system of pneumatic-carrier tubes converging to a central station are all operated from the same air-pump and receiver.

In this system, when the tubes are not in actual use making

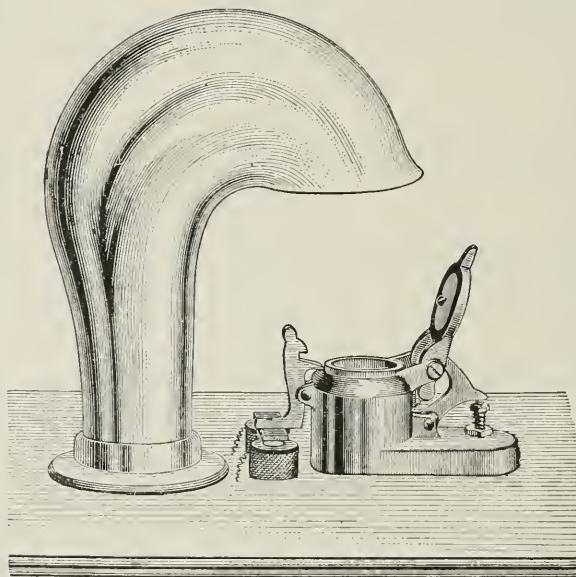


FIG. 489.—THE COUNTER STATION.

transmissions, they are open at both ends to the atmosphere, and can be used as speaking-tubes. They are in use in some of the largest buildings in our cities, notably the Waldorf-Astoria Hotel. Single lines are in use 1,200 feet between terminals.

The counter station (Fig. 489) is used for store service and office counters, showing tube, terminal, and metallic hood. The valve is released by an electro-magnet, which throws the catch off the cover and is operated by a key at the other terminal.

Fig. 490 shows the operating mechanism of the automatic

terminal valve and its air-pressure lock. As soon as the carrier is expelled from the tube, the closed cover automatically opens to the position shown in the valve represented on the left-hand side of the cut. The pressure is automatically shut off by the opening cover, and the tube is then open at both ends to the atmosphere, and stands ready to transmit carriers from either end to the other end, and while not in actual use it consumes no power. The tube can open downwardly at the ends, or upwardly, as shown in the hand-operated terminal (Fig. 491). The adjacent connection with the pressure-supply pipe is opened by shutting the cover, and automatically is held open while the cover remains

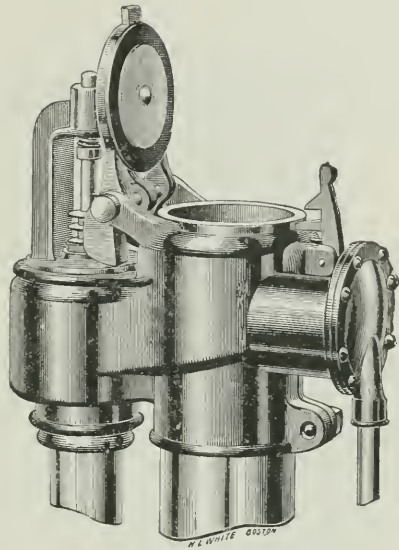


FIG. 490.—AUTOMATIC TERMINAL VALVE.

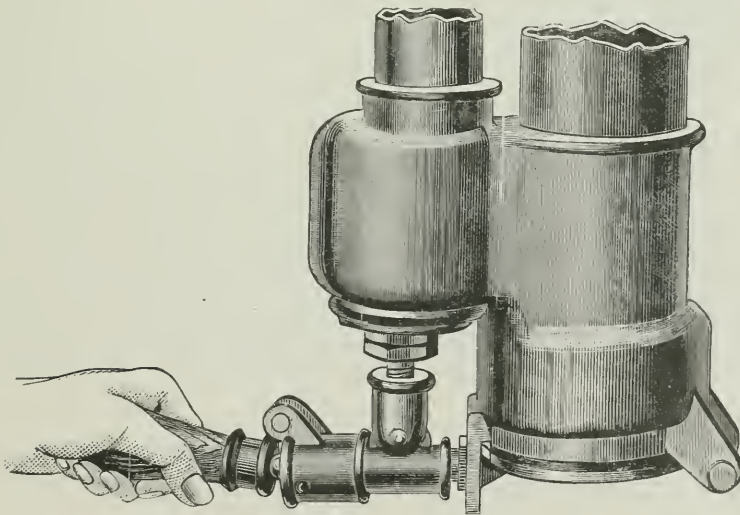


FIG. 491.—HAND-OPERATED TERMINAL VALVE.

closed. The air pressure running freely into the tube forces the carrier immediately through the tube.

In Fig. 492 is represented an automatic terminal of a store or office pneumatic despatch or cash-carrier tube with a catch basket. The cover is thrown open which closes the air-pressure inlet of the supply pipe and is ready for the ejection of

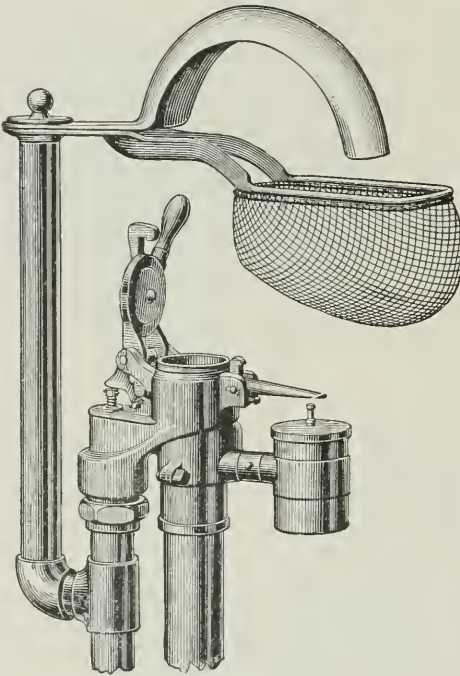


FIG. 492.—AUTOMATIC TERMINAL.
With catch basket.

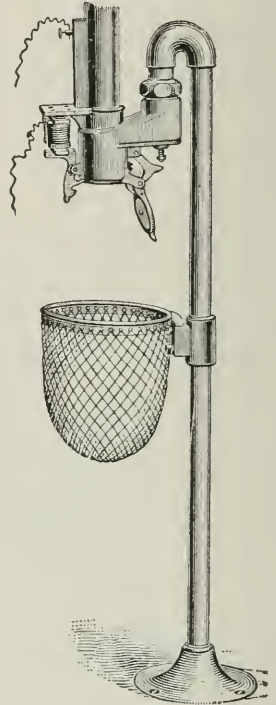


FIG. 493.—FLOOR STATION.

the tube messenger or carrier. The small cylinder at the right contains a piston with a projecting rod that unlocks the cover catch by the air pressure when the carrier passes cross-connection and is approaching the valve.

In Fig. 493 is shown a floor-stand which is also the air-pressure pipe, with the carrier pipe dropping from the ceiling and discharging into a basket. It has an electric automatic opening device and lock attached.

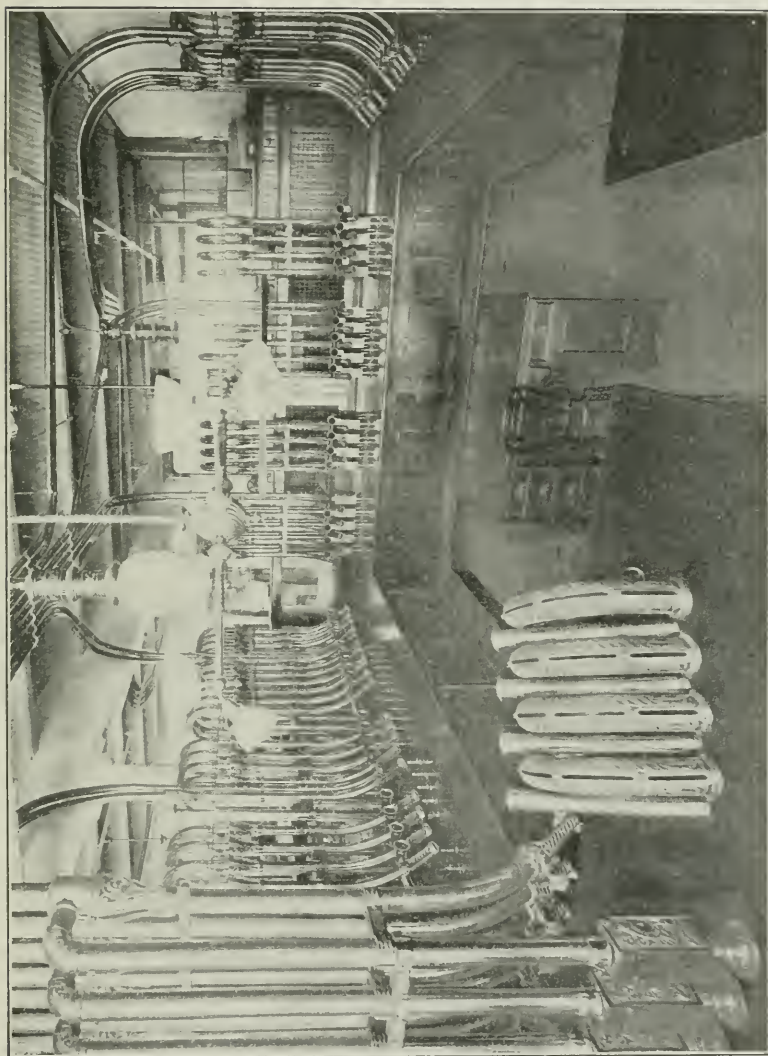


FIG. 494.—PNEUMATIC TUBE SYSTEM IN A DEPARTMENT STORE.

The Peasall Pneumatic Tube and Power Company, 154 West 27th Street, New York City.

Chapter XXXI.

COMPRESSED AIR IN
WARFARE

COMPRESSED AIR IN WARFARE.

THE PNEUMATIC DYNAMITE GUN.

AFTER many years of experiment in the fruitless endeavor to throw a dynamite torpedo from a gun with powder or other explosive, Mr. D. M. Mefford, of Ohio, seems to have been the first to indicate the correct solution of the problem, by applying compressed air as the propelling force in his pneumatic dynamite gun. The first gun, which was of 2-inch bore by 28 feet in length, was tested by Lieut. E. L. Zalinski in New York harbor in 1884, using an air pressure of 500 pounds. A range of one and one-quarter miles was obtained with an accuracy and precision surprising when the crude method of construction and the handling of the air valve is considered, which latter was largely due to the personal equation of the gunner for different discharges.

Encouraged by the success of these experiments, a 4-inch gun was built, in which air pressure at 1,000 pounds per square inch was used, and in which an improved form of air valve was made automatic in action and capable of delivering uniform amounts of air. In experiments with this gun the practicability of throwing dynamite cartridges with an air pressure of 1,500 pounds per square inch was settled beyond dispute.

During these experiments Lieutenant Zalinski developed the electric fuse, which largely contributed to the efficiency of the gun. An 8-inch gun, 60 feet in length, capable of throwing a shell containing 100 pounds of explosive to a distance of two miles with an air pressure of 1,000 pounds, was then built and mounted at Fort Lafayette in 1885; which we illustrate in Fig. 495, giving a general view and details.

To secure rigidity of barrel it is mounted on a truss, the

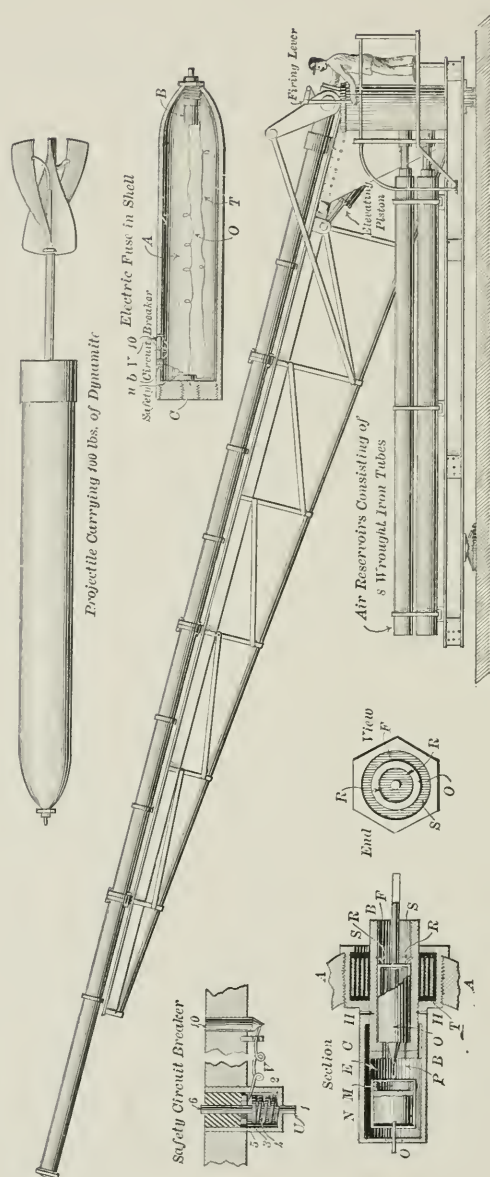


FIG. 495.—THE ZALINSKI PNEUMATIC DYNAMITE GUN.

With detailed parts of projectile, exploding device, and safety circuit breaker.

whole turned upon the breech trunnions in the act of elevating by means of a ram acting against the heel plate of the truss. The trunnions rest in two hollow upright castings supported upon the chassis. The castings also act as air connections between the eight 12-inch by 22-feet tubes forming the firing reservoir, said tubes being secured on chassis and turning with it. The chassis is a front pintle arrangement similar to those in use for heavy powder guns.

Upon the chassis are also mounted the cylinders for giving side train.

The air supply from the magazine reservoir into which the compressors deliver, is carried through the pintle around which the gun trains, into the firing reservoir mounted on the chassis.

The firing valve, placed in the head of one of the trunnion supports, is capable of adjustment, to cut off the air at any desired point in the barrel for varying ranges. It should be borne in mind that at each discharge only a small per cent of the air in the firing reservoir is used, and if desired the original pressure of 1,000 pounds can be immediately restored while loading for the next shot, by opening the connection between the firing and the magazine reservoirs, the latter always being maintained at a higher pressure. By this method the firing can take place as rapidly as the shell can be loaded and the gun aimed; the best record for speed being the discharge of five projectiles in nine minutes and forty seconds.

The system is also capable of greater accuracy (within the limits of its range) than powder guns; the initial pressure in powder guns varying with the condition and age of the powder and temperature of gun at instant of firing; whereas, in the pneumatic gun, with a known initial pressure and point of cut-off, the resulting range must necessarily be constant for any given weight of projectile and degree of elevation.

The fact that the gunner has under his immediate personal control all movements necessary to bring the gun to bear on the enemy without removing his eye from the sight increases

the speed with which accurate shots can be delivered. The 8-inch gun was worked constantly, for experiment and exhibition, at 1,000 pounds pressure for sixteen months, delivering in that time a greater number of shots than it would be possible to fire from a powder gun without either destroying or rendering it unserviceable.

At an elevation of 35° , shells containing 60 pounds of explosives have been repeatedly fired $2\frac{1}{4}$ miles; and at an elevation of 33° , shells containing 100-pound charges have attained a range of 3,000 yards.

In the lower left-hand corner of the cut (Fig. 495) is shown the section of the detonator at the point of the shell. The fuse *B* contains an electric battery in the small case *O*, composed of chemicals in a dry state. The battery has a penetrating point, *P*, which when driven in contact with the insulated plunger *M N*, to which the circuit wire *O* is connected and the circuit completed through the circuit-breaker, fires the cap at *C* in the rear of the charge. There is much detail in the arrangement not necessary to explain here, by which the shell is exploded on a time circuit or by impact upon the hull of a vessel.

In Fig. 496 is illustrated the pneumatic gun invented by Lieut. J. W. Graydon, U. S. N. It differs from the Zalinski gun in being very much shorter and designed to be operated under a pressure of 3,000 pounds per square inch. In a field-piece as shown in the cut the high-pressure air bottles or cylinders are fixtures of the gun and carriage, and have air capacity for the discharge of a number of shots.

The capacity of the bore of a 3-inch field-piece, 10 feet in length, would be something less than a half cubic foot, including the projectile, and would require less than a fourth cubic foot of compressed air for discharging a projectile at 1,500 pounds air pressure. A battery of six bottles 4 inches in diameter and 5 feet in length would contain enough air at 3,000 pounds pressure for twelve shots.

Another form of pneumatic gun was brought out by Mr. Dana

Dudley, the "Powder Pneumatic Gun," in which the air was compressed at the moment of firing by a powder charge; thus dispensing entirely with the ponderous air-compressing machinery and better adapting the gun to field service for firing torpedoes. It consists of a gun barrel of light weight connected at the breech with a tube of similar bore reaching forward and connecting with a stronger tube all lying parallel with and beneath the gun. A torpedo is placed in the breech of the gun just beyond the air inlet, and a powder charge in the explosion tube just beneath the gun breech. On firing the powder charge the air is compressed in the forward part of the firing chamber

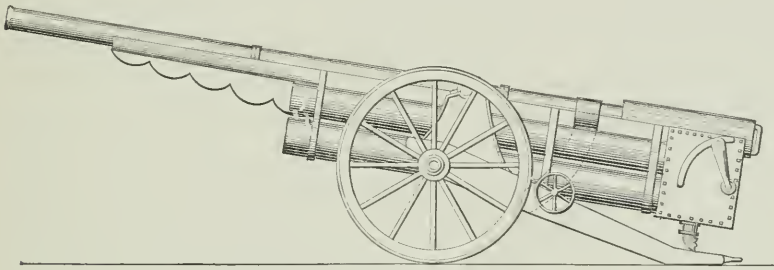


FIG. 496.—THE GRAYDON PNEUMATIC GUN.

and in the connecting tube, generating a pressure of from 800 to 1,000 pounds per square inch. The force of the explosion, cushioned by the two columns of air intervening between the powder and the projectile in the central tube, acts upon the projectile. With a slight noise and without a particle of smoke or flame the projectile is driven out of the barrel and passes smoothly through its trajectory. About the same effect is attained as with the regular pneumatic gun. The extensive air-compressing plant of the latter is, in the case of the Dudley gun, represented by a simple blank cartridge.

Compressed air is now used for controlling the recoil of guns and mortars, and in the operation of loading, elevating, and traversing mortars and guns in fortifications it has been proved effective and a most convenient and labor-saving element in the operating of engines of war.

COMPRESSED-AIR SYSTEM ON THE UNITED STATES MONITOR
"TERROR."

The use of compressed air as a motive power on board a warship presents several advantages over steam or hydraulic power, which renders it a powerful competitor. As compared with steam, it is less dangerous, especially during an action, when a broken steam-pipe might prove terribly fatal, and it enables certain parts of the ship to be kept at an even temperature which would otherwise be rendered uncomfortably hot by the presence of steam-piping. Steam and hydraulic engines, moreover, require exhaust pipes discharging outside the hull of the ship; whereas the exhaust from the pneumatic cylinders may be turned into the ship or into the outside air, as may be most convenient. There are certain localities in a ship where the exhaust from a pneumatic engine would prove a valuable source of ventilation, as, for instance, in a turret crowded with men and machinery, or in the close confinement of a steering room situated below the protective deck. As compared with hydraulic power, the compressed-air system is cleaner and more convenient, and free from the discomfort that arises from the leaking of hydraulic pipes and cylinders.

In 1890 the Navy Department authorized a complete pneumatic system for steering the monitor *Terror* and operating her turrets. Owing to delays in the completion of the ship, the new system was not tried until late in 1896, when the whole of the elaborate plant was put to a thorough test at sea, and gave the greatest satisfaction to the naval experts. As the *Terror* was the first vessel in the world to be so equipped, there was considerable anxiety as to the success of the experiment; but now that the plant has demonstrated its ability to do all that was claimed, its success has stimulated the use of compressed air in similar lines in the navies of Europe.

Directly below the centre of the turret is a pneumatic load-

ing machine, which rotates upon a vertical shaft, and may be swung to the right or left as desired. The 500-pound shell and the cartridge, the latter in two parts, are run out from their respective rooms on a overhead trolley and placed in the tray of the loading machine, as shown in Fig. 497. The tray is pivotally attached to the body of the machine by a set of par-

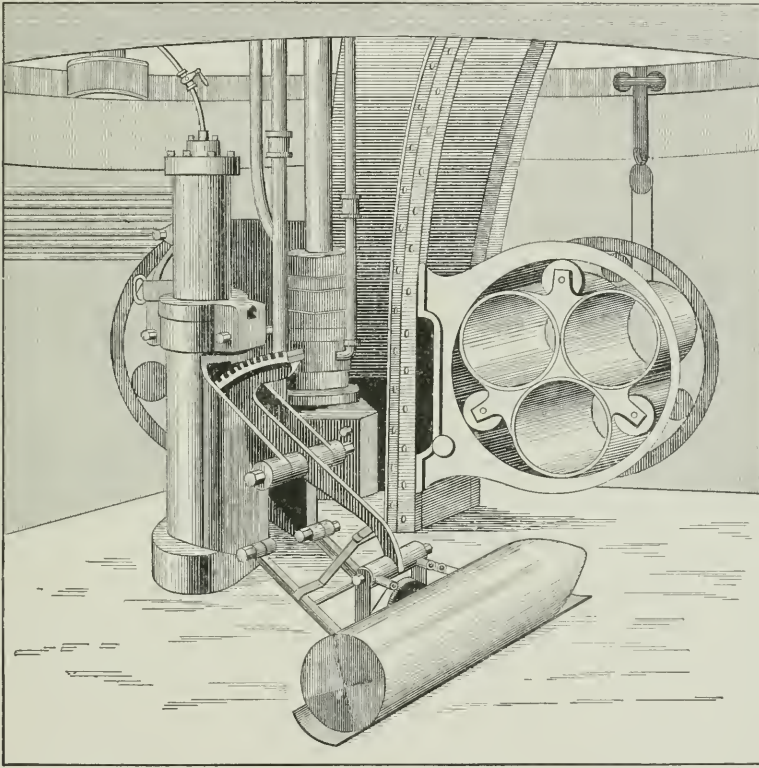


FIG. 497.—AMMUNITION ELEVATOR AND PNEUMATIC LIFT FOR LOADING THE ELEVATOR.

allel rods and a lever which carries at its inner end a circular rack. Above the rack is an air cylinder whose piston rod terminates in a vertical rack which engages the circular rack. By admitting air at the top of the cylinder, the tray with its load is raised to the required height and the latter is placed in the pockets of the loading car.

There are two of these cars, one for each gun, and they

travel upon two vertical hoists or trackways which lead up to the breech of the guns. The hoisting is done by two pneumatic cylinders located on the floor of the turret between the guns. Attached to each piston rod and beneath each cylinder is a set of multiplying sheaves. Over these passes a wire rope, one end of which is fastened to the floor of the turret, the other end being carried to the loading car. The speed of the rope is so adjusted that the full stroke of the pistons will serve to hoist the loading car from the floor of the handling room to the breech of the gun.

By reference to Fig. 497, it will be seen that the loading car contains three parallel pockets, which rotate within the frame of the car, friction wheels being interposed to facilitate the movement. One of the pockets carries the shell and the other two the powder charge. The car is automatically brought to a stop with the lowest pocket containing the shell immediately in line with the breech of the gun.

It is then pushed home by a telescopic rammer which is operated by compressed air, the valve which admits the air being worked by a man who sits astride of the cylinder (Fig. 498). It will be noticed that the rammer is carried by a bracket bolted to an extension of the gun carriage, and it is consequently held at all times in true line with the bore of the gun. After the shell has been rammed home, the loading car is rotated and the two sections of the powder cartridge are brought successively opposite the breech and pushed home. The breech plug is then swung round, thrust into place, and locked.

The air for driving the various pneumatic devices is compressed by two separate engines, one being placed in the hold near the forward turret and the other near the after turret on the berth deck. The working pressure is 125 pounds per square inch, and there is no reservoir for the air except an 8-inch pipe, which runs through the vessel and supplies the two turrets and also the steering device in the steering-room at the extreme after end of the ship. These two engines supply suffi-

cient air for turning the turrets, elevating the guns, lifting the ammunition into the cages, raising the cages to the breech of the gun, ramming home the charge, closing the breech, checking the recoil, and, lastly, and most important operation of all, steering the ship itself.

The two turning engines are placed upon the floor of the turret, one on each side of the big guns. Each engine has two

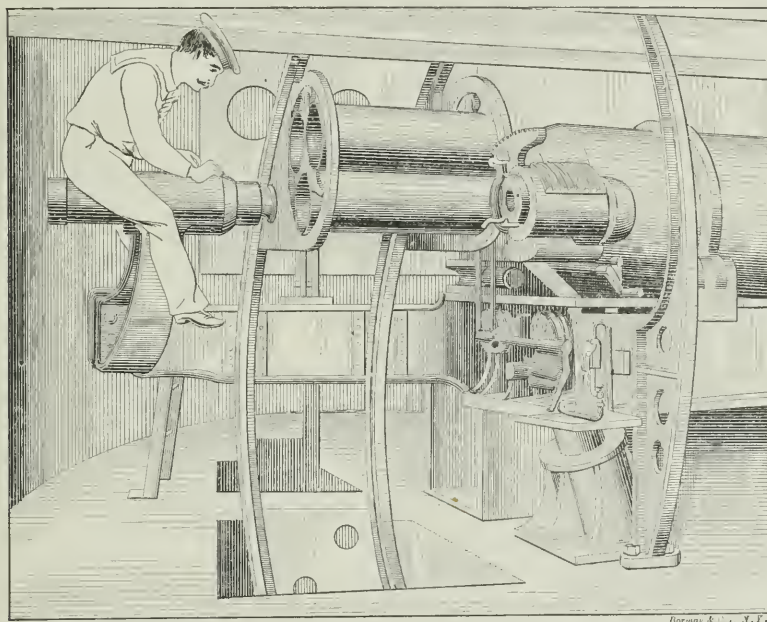


FIG. 498.—CHARGING THE GUN: THE LOADING CAR IS BETWEEN THE TELESCOPIC RAMMER AND THE BREECH OF THE GUN.

cylinders, 8 inches in diameter by 14 inches stroke. A worm on the crank shaft operates a set of gears by which the power is multiplied many times over before it reaches a driving pinion, which, in common with the engine and gears, is firmly bolted to the framing of the turret and turns with it. The pinion meshes with a large circular rack which is bolted to the deck of the ship and lies immediately within the circular steel track upon which the turret rotates. The engines are controlled by suitable levers and hand-wheels situated within easy reach of

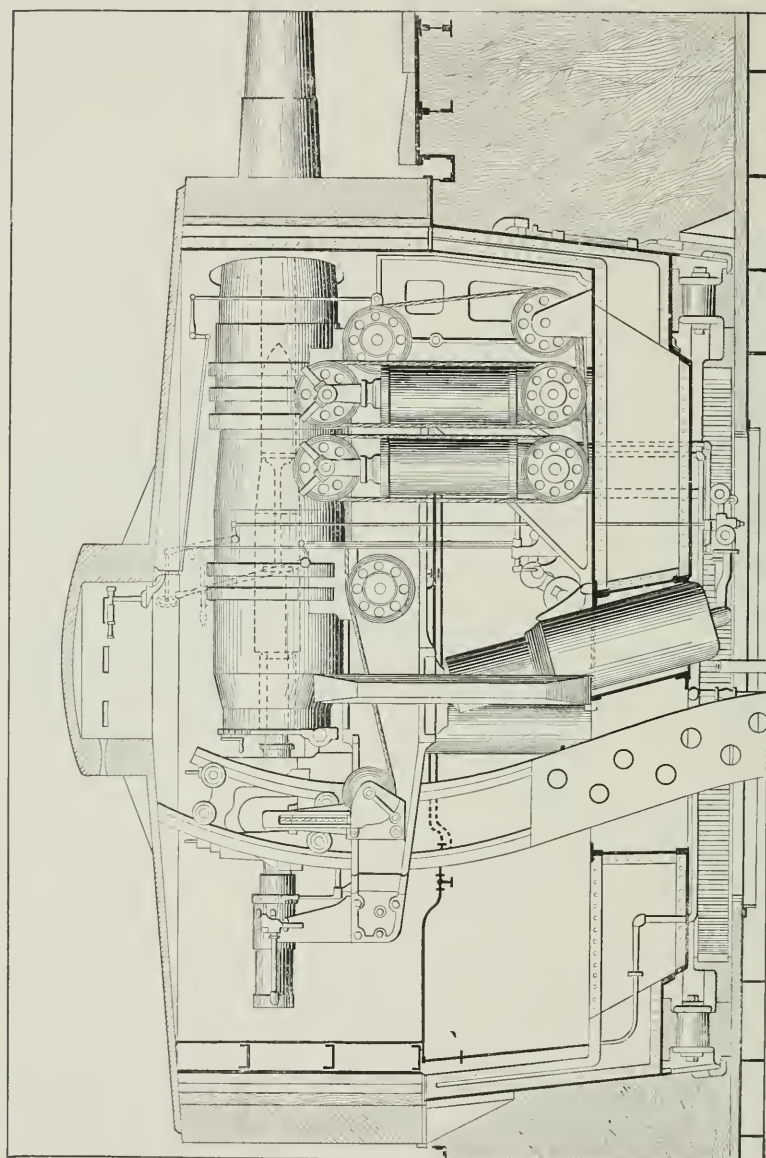


FIG. 499.—PNEUMATIC SYSTEM FOR HANDLING THE 10-INCH GUN ON THE MONITOR "TERROR."

the officer in the sighting hood, the latter being placed over and between the guns.

The elevation and depression of the gun are effected by means of a massive ram, which is hinged to the floor of the turret and bears against a shoe on the under-side of the gun carriage near the breech of the gun. On each side of the turret is a cylinder containing glycerin and water, a portion of which, when the gun is to be elevated, is forced by compressed air into the ram, the supply being regulated by valves which are operated by means of levers in the sighting station. With his eye at the telescope and his hand upon the levers which control the air valves of the turning and elevating machinery, the officer brings the cross-hairs of the telescope to bear upon the mark, and by pressing an electric button hurls a 500-pound steel projectile with unerring precision at the hostile ship.

The recoil of the gun is controlled by two pneumatic cylinders, 14 inches in diameter and 40 inches in length. The cylinders below the breech are secured to the gun carriage and the pistons to the gun. Before firing, the pressure on the recoil side of the pistons is about 500 pounds per square inch. As the gun recoils, carrying the pistons with it, this pressure is rapidly increased by compression. To reduce the pressure at the end of the recoil, a tapered rod is provided, which passes through the centre of the piston and allows the air to pass more and more freely to the counter side of the piston as the gun returns. The residual pressure is utilized to return the gun to its firing position. Perhaps there is no part of the many operations performed by compressed air on the *Terror* in which the power shows to better advantage—the elasticity of the air preventing all shock and providing an easy cushion in the recoil and counter recoil.

The last and most important duty performed by the compressed air is that of steering the ship. The work is performed by two long horizontal cylinders which are arranged one on each side of the tiller. They are provided with a common

piston rod, in the centre of which is a hollow crosshead in which the tiller is free to slide as it is swung right or left by the movement of the pistons. Compressed air is admitted to the outer ends of the cylinders by means of a D valve, the air being simultaneously admitted at the back of one piston and exhausted from the other, according as the helm is to be put over to port or to starboard. Air is also admitted at all times at the inner ends of the cylinders, and a pipe connects them,

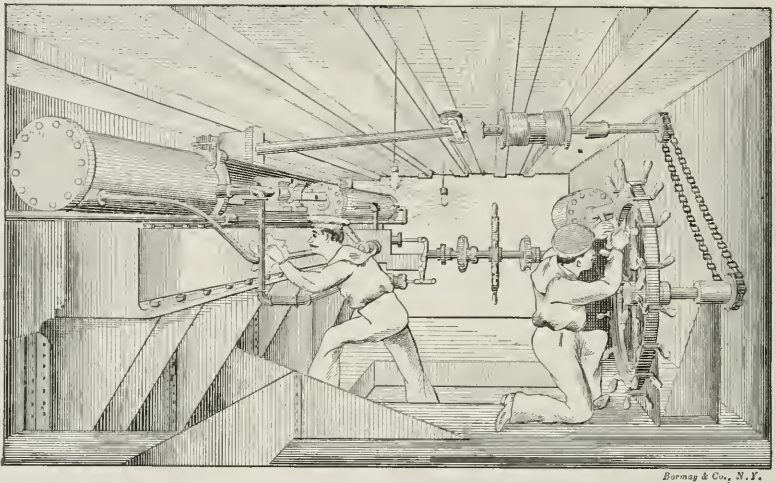


FIG. 500.—PNEUMATIC STEERING APPARATUS ON THE MONITOR "TERROR."

so that, as the pistons move, the air may flow freely from the inner end of one cylinder to the inner end of the other. In the centre of the connecting pipe is a by-pass valve, which is open when the tiller is being moved, but closes when it has been traversed the desired angle, and holds the air imprisoned in the cylinders, thus locking the tiller between two elastic cushions. The heavy shocks to which the tiller is subject in rough weather will thus be received and absorbed by the air, and the framing of the ship will be proportionately relieved of the strain.

The general use of compressed air on shipboard may not in many cases be as economical as steam, but considering for all

emergency cases and where a constant pressure is required at points distant from the boilers, there is nothing equal to compressed air for operating auxiliary fire, bilge, and water service pumps; steering engine; anchor engine; boat cranes; winches; turret-turning engines; hydraulic cylinders for working guns; ammunition hoists; ash hydropneumatic hoists; feed pumps; smoke hose for guns; whistle and siren; to send messages; to clear a compartment of water when flooded; to ventilate and to heat and cool the ship.

Compressed air is better than steam for auxiliary use on board ship, for the following reasons:

The ship is cooler in summer, and men are not debilitated by the heat; there are no hot bulkheads all over the ship; the auxiliary machinery and pipes last much longer; half the number of valves, pipes, etc., are needed; there are no ventilating blowers needed to neutralize the heater lines doing the work; there is great saving in cost of plants and in the cost of oil; no pipe coverings are needed; the machines are ready for use at once; there are fewer men on watch in port, and more for general work.

Chapter XXXII.

COMPRESSED AIR WORK

COMPRESSED AIR WORK.

COMPRESSED AIR FOR RAISING WATER.

THE air-lift pump is said to have been invented in the eighteenth century and in use at Freiberg, Saxony. Siemens in England experimented with the air lift in the middle of the nineteenth century, and it was patented as an air ejector by McKnight in 1864. The principle of its action became a theme with Dr. J. G. Pohlé, and to whom two patents were issued, Nos. 338,295 and 347,196, covering the system of elevating water by admixture of air under compression suitable for the height that the water was to be raised. This system, however, required a depth of water in the well more than equal to a height to which the water was to be lifted.

The original Pohlé system has been modified and improved with a number of patents on special points in the system with small gains in efficiency. Dr. Pohlé also introduced compounding or stage-lifting, which has been made available to such an extent that it is now possible to lift water to great heights from an ordinary sump in a mine or from ordinary wells.

We illustrate in Fig. 501 the compressor, receiver, air and lift pipe as usually operated in deep wells, in which the pressure in the air pipe must be greater than the hydrostatic pressure of the water at the bottom of the pipe, and in quantities sufficient to make the ascending column of air and water in the flow pipe lighter in its total height than the weight of an equal column of solid water of the depth of the well from the surface of the water to the bottom of the pipe, thus making this principle in pumping water essentially a differential gravity system.

The air-lift pump proper consists of only two plain open-ended pipes, the larger one with an enlarged end piece consti-

tuting the discharge pipe, and the smaller one let into the enlarged end piece of the discharge pipe constitutes the air inlet pipe, through which the compressed air is conveyed to the enlarged end piece to the under side of the water to be raised. No valves, buckets, plungers, rods, or other moving parts are used within the pipes or well.

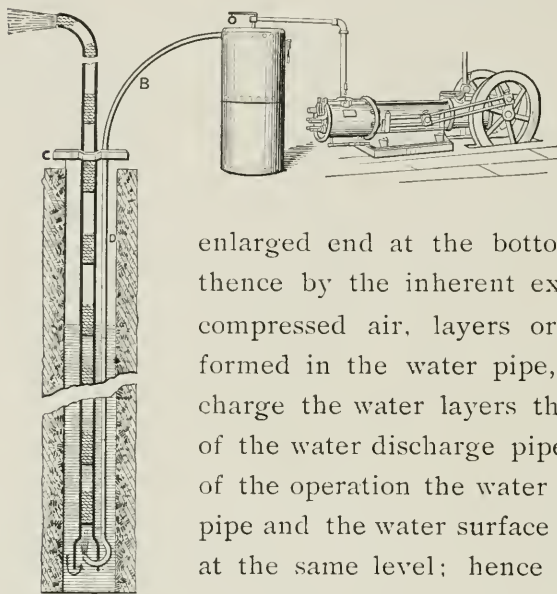


FIG. 501. — AIR-LIFT PUMP.

In pumping, compressed air is forced through the air pipe into the enlarged end at the bottom of the water pipe; thence by the inherent expansive force of the compressed air, layers or bubbles of air are formed in the water pipe, which lift and discharge the water layers through the upper end of the water discharge pipe. At the beginning of the operation the water surface outside of the pipe and the water surface inside of the pipe are at the same level; hence the vertical pressures per square inch are equal at the submerged end of the pipe, outside and inside. As air is forced into the lower end of the water pipe, it forms alternate layers with the water, so that the pressure per square inch of the column thus made up of air and water, as it rises inside of the water pipe, is less than the pressure of water per square inch outside of the pipe.

Owing to this difference of pressure, the water flows continually from the outside to within the water pipe by gravity force, and its ascent through the pipe is free from shock, jar, or noise of any kind.

These air sections or strata of compressed air form closed bodies, which, in their ascent in the act of pumping, permit no slipping or back flow of water. As each air stratum progresses upward to the spout, it expands on its way in proportion

as the overlying weight of water is diminished by its discharge, so that the air section, which may have been say 50 pounds per square inch at first, will be only 1.74 pounds when it underlies a water layer of four feet in length at the spout; until finally this air section, when it lifts up and throws out this four feet of water, is of the same tension as the normal atmosphere; thus proving that the whole of its energy was used in work, and that this pump is a perfect expansion engine.

As the weight of the water outside of the discharge pipe (the head) is greater per square inch than the aggregate water

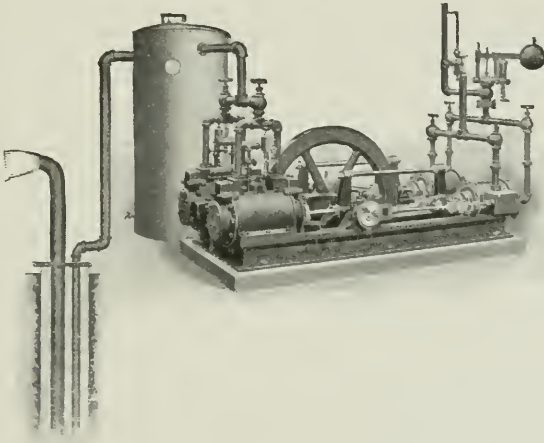


FIG. 502.—THE CLAYTON DUPLEX AIR COMPRESSOR AND AIR LIFT PUMPING APPARATUS.

sections within the pipe when in operation, it follows that the energy due to this greater weight is utilized in overcoming the resistance of entry into the pipe, and all the friction within it.

The Pohlé "air-lift" pump has been found to give above 80 per cent of efficiency from the air receiver in water pipes of large diameter, and, as a rule, above 70 per cent in small-sized pipes. It retains this efficiency without repairs, or until the pipes rust through, whereas ordinary bucket-and-plunger pumps gradually lose efficiency from the first stroke they make, and lose it rapidly if the water contains sand or is acid in character.

The secret of the air-lift pump action is in the high velocity with which the air and water are discharged through the education pipe. Without this high velocity there would be no piston-like sections except perhaps in a small glass tube model where capillary attraction takes the place of velocity.

As the pump has no valves, no standing water remains in the pump column after the operation of pumping; it recedes into the well, and there is none left to freeze in cold weather. The capacity of the pump is unlimited, and, with the proper proportions of air to the water, will work efficiently in pipes several feet in diameter. Estimates have been made which indicate that a 30-inch pipe will deliver 16,660 gallons per minute, equal to 1,000,000 gallons per hour.

As sand, silt, gravel, and bowlders in water form no obstacles to interfere with the action of the pump, its adaptability for dredging is suggested as well as its utility for pumping sewage. Experience has proved that, by the use of this constant upward flow of water, artesian wells have been freed from their accumulated sedimentary deposits, as well as that lodged in the fissures and crevices of their wall rock, and have been thus made to yield greater quantities of water than they ever did before. For chemical uses, and for the liquids of the arts, there is no superior method than the "air lift." It is used successfully for raising sulphuric acid of high specific gravities, and is well adapted for ore-leaching works, vinegar works, sugar refineries, dye works, paper-pulp works, etc.

As an irrigating pump for raising subterranean water in the arid regions of the West, its field of usefulness is very promising, for with one air-compressing plant at a central station, a number of wells, widely separated from one another, may be simultaneously pumped by branches of air-conveying pipes, taken from a main air pipe from the air compressor; for compressed air may be conveyed for miles without material loss of power.

It often happens that a single well does not yield the quan-

tity of water desired, but that a number of wells would give the satisfactory result. By the old-fashioned deep-well pump, each well would require a separate "steam head," separate sets of rods, and the other paraphernalia, which, with the condensation of the steam, when conveyed to the several steam heads, would be very costly in the first outlay, and very wasteful of power in its maintenance, to say nothing of loss of time in repairs. By the Pohlé process, but one air-compressing plant is required, and this may be placed in the engine room or the boiler house, directly under the eyes of the engineer, from whence the air may be conveyed to the several wells, all of which may be pumped simultaneously and economically.

In Fig. 501 is illustrated the air-lift system of the Ingersoll-Sergeant Drill Company, New York City, with which company Dr. Pohlé was associated in the last years of his life.

In the early trials for efficiency of the air lift some curious comparisons were brought out relative to the ratio of the lift to the depth of submersion and the relative air pressure due to submersion.

Thus with 16 pounds air pressure with 41 feet water lift and 10 feet submergence, 68 cubic feet of free air per minute lifted $\frac{7}{8}$ cubic foot of water 41 feet high, giving a computed efficiency of $3\frac{1}{2}$ per cent of the steam power. The efficiency was found to decrease with the increase of air pressure above what was necessary to do the work; for instance, with an equal submergence and lift of 26 feet and an air pressure of 20 pounds, 64 cubic feet of free air pumped 14 cubic feet of water 26 feet high per minute, showing an efficiency of 19 per cent of the steam power in the compressor. When the air pressure was reduced to $12\frac{1}{2}$ pounds, using 26 cubic feet of free air per minute and pumping $8\frac{1}{2}$ cubic feet of water 26 feet high per minute, the efficiency was raised to 42 per cent. It was found on trials that on a deeper submergence of 1 to 1.6 the efficiency rose to 53 per cent, and in all trials was greatest at the lowest pressure that the lift could be operated. It was found on a general aver-

age that the efficiencies that may be expected from the best conditions for air compression may be stated as follows:

$$\frac{\text{Height}}{\text{Submergence}} = .5 \text{ efficiency } 50 \text{ per cent.}$$

1.0	“	40	“
1.5	“	30	“
2.0	“	25	“

Mathematicians have formulated some complicated equations in relation to the action of the air in the ascending column of water; but as the air bubbles vary in size according to the form of the injecting nozzle, and as their coalescence and expansion produce so many variable factors, reliable results can be obtained only from actual tests, and even these are merely approximate.

In a test of the Pohlé air-lift made at De Kalb, Ill., the air pipe was placed inside of the well pipe with a water lift of 133 feet, and the submerged nozzle 123 feet below the surface, a nearly equal ratio. The well pipe was 6 inches diameter, air pipe $2\frac{1}{2}$ inches, thus adding about 50 per cent to the friction of the ascending water and giving to the whole length of 256 feet an irregular annular space for the passage of the water and air. With the expenditure of 42.7 horse-power indicated, there was raised 207 gallons of water 133 feet, with a volume of 310 cubic feet of free air per minute. The efficiency was found to be $17\frac{1}{2}$ per cent. This shows very plainly that the friction of an internal air pipe causes a loss of efficiency.

A series of trials with a gang-well system on the Pohlé plan was made at Rockville, Ill. In casings of $6\frac{1}{4}$ inches diameter inserted in four wells, 260 feet below the overflow, and air pipes $1\frac{1}{2}$ inches diameter, let down 250 feet, all in 8-inch drilled wells. After several trials with return bends and small nozzles at the bottom of the air pipes with unsatisfactory results as to water flow, the bottom of the air pipe was closed and the sides slotted for 20 inches up from the bottom, giving a full and free opening for the air without any obstruction to the upflow of the

water. In this manner the service was raised from 1,000 gallons to 1,400 gallons per minute, but still showing an efficiency of only 24 per cent.

Much doubt has existed from the early years of the air-lift system as to the possibilities in regard to conveying the water to a distance or direct to an elevation at a distance from the well. Lately there has been constructed at Point Pleasant, W. Va., on the bank of the Ohio River, a water-works employing the air-lift system to obtain water filtered into the gravelly soil beneath the river. The compressor was located in a power

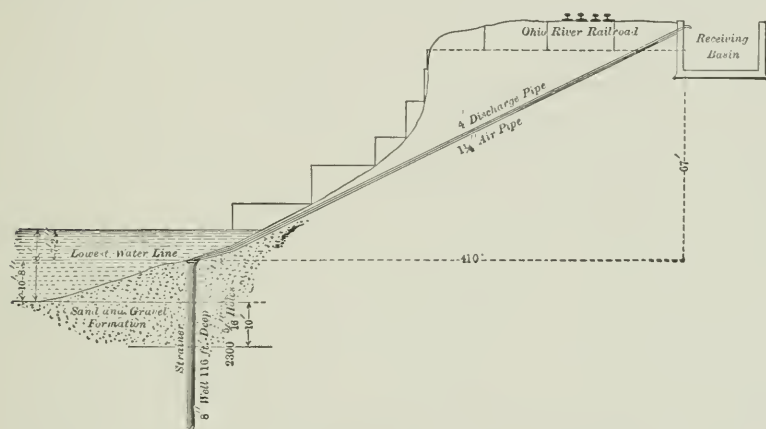


FIG. 503.—PROFILE OF THE POINT PLEASANT WATER-WORKS.

house 500 feet distant from the location of the wells on the river bank. The receiving basin is situated at the top of the river bank, 67 feet above the top of the well pipes and 400 feet from the low-water bank of the river. In Fig. 503 is shown a profile of the situation. Well casings 10 inches in diameter were driven to the rock about 40 feet in depth.

After the 10-inch casings were in place 10-inch holes were drilled in the underlying rock 116 feet deep, and cased 8 inches inside diameter from bottom to top. This casing was also perforated similarly to the outer one, only the holes were larger— $\frac{5}{16}$ inch. The space between the two casings was tightly calked at the top to prevent water entering the wells at this point.

Four-inch discharge pipes and $1\frac{1}{4}$ -inch air pipes were properly fitted and suspended in each of the wells, with their extremities 110 feet below the top of the 8-inch casing.

Both pipes were suspended from a water-tight cap, resting on the top of the 8-inch casing. It will be observed that no water can enter these wells except through the perforations in the casings, which are 10 feet to 20 feet below the flowing water in the river. None can enter at the bottom. It was the desire to allow the river water to enter the wells only through the perforations after having passed through the sand strata mentioned, which would serve as a filter; which has proved that, however muddy the river may be, the water taken from the wells is bright and sparkling at all times.

Just when the wells were completed and the pipes in place and extending up the sloping river bank a short distance, the river rose over the wells. For two months the wells stood unused. In the mean time the reservoir, receiving basin, and power house were completed, and the work advanced as fast as possible. Just as soon as the air compressor was in place the air pipes were connected up and the wells tested before the discharges were extended to the receiving basin. One well was found with a deposit of sand in the bottom reaching 5 feet above the foot of the discharge pipe. Several unsuccessful efforts were made to force air into this well. The river having receded, the air pipe was disconnected at the top of the well and a $\frac{3}{8}$ -inch gas pipe coupled and lowered. It stopped 5 feet from the bottom. It was churned a few minutes and soon went down the remaining 5 feet. Again the air pipe was coupled and the air pressure increased to 90 pounds per square inch. The effect was almost startling, but gratifying. The obstruction was cleared out very quickly. No other system of pumping could possibly have accomplished the clearing out of this well of the sand deposit.

The discharge and air pipes to each well are independent. That is, each well has a separate discharge to the receiving

basin and a separate air pipe from the receiver. These are carefully graded and are not exposed at any point except where the discharges pass through the top of the walls of the receiving basin, and have open discharge.

The working pressure is from 45 to 50 pounds, varying with different river levels.

The discharge of water is not constant, however, but irregular or intermittent, as though the air and water formed alternate strata or volumes within the discharge pipes. It varies with the depth of water in the river, ranging from 1 volume of water to 8 volumes of free air, to 1 to 6. As the river is constantly rising and falling and is frequently 25 to 40 feet deep over the wells, the pressure on the sand surrounding the wells is constantly changing and affects the capacity of them as well as the necessary air pressure to pump them.

The reservoir is situated about $1\frac{1}{2}$ miles distant and at 225 feet elevation. Water is taken from the receiving basin by belt-driven triplex outside-packed plunger pumps, 9 inches diameter by 12-inch stroke, operated at 37 revolutions per minute, delivering about 22,000 gallons per hour.

As there is no demand in the town for electric current during the day, the works are operated at night only. Usually the air compressor is operated one night, and the following night the forcing pumps. The water received the previous night in the settling or receiving basin has about twelve hours to become cleared of any sand brought with it from the wells before going to the reservoir. This basin has a capacity of about 225,000 gallons; the reservoir about three times this quantity. The construction of the receiving basin is the same as the reservoir. The engine has ample power to operate all the machinery at the same time. Two men only are required to attend the combined plant. In addition to the public and private consumption of water, two busy railroads are consumers. All customers are served by meter, and therefore there is practically no waste.

There can be no doubt that water taken by air in this manner is purified to some extent, the admixture of air serving to oxidize and destroy organic matter. Samples of the water taken are bright and sparkling, have no odor, and remain apparently unchanged. There probably is not another town of 5,000 inhabitants in the country that has a better or more complete combined water and light works. Certainly there is not another town of any size on the banks of the Ohio River from Pittsburg to Cairo that has better water, if as good.

The works have been in constant operation since built.

What has been accomplished at Point Pleasant can be done at hundreds of other small towns similarly situated where there is no water-works. Here it has been demonstrated that bright, sparkling water can be obtained from a muddy, filthy stream without the use of chemicals or mechanical filters.

Just use the filter nature has so abundantly supplied at the bottom of such streams, and by proper arrangement of the pumping system combined with an electric-lighting system, thus economizing the operating expenses to a minimum, establish first-class water and electric service on a paying basis when neither separately would pay operating expenses.

The air-lift system is undoubtedly the simplest as well as the best of all known methods of serving such towns with good water. Nor is the system less applicable to larger towns, as well as to factory and domestic supply.

Artesian wells, or wells supplied from land sources, generally yield hard water or water highly charged with mineral salts. The water at Point Pleasant is soft, pleasant, and wholesome. The railway companies using it speak very highly of it. It is simply Ohio River water freed of filth and all objectionable matter that render it so disgusting at many towns along the stream.

THE COMPOUND AIR LIFT.

The idea of compounding the air lift was first proposed by Dr. Pohlé, and has since come into use for shallow sumps. Fig. 504 represents the conditions of a sump of about one-quarter of the total lift in depth, in which an auxiliary pipe is introduced to receive the water at about twice the depth of the sump to act as a pump well for a higher lift. By this method the inconvenience and cost of a deep shaft or boring may be avoided and the compound system quickly applied in emergencies.

As yet we have no data as to its efficiency for permanent use, but there is no doubt that economy due to decreased air pressure will be found to warrant its adoption in mine and drainage work.

MULTIPLE STAGE AIR-LIFT PUMPING.

In Fig. 505 we illustrate the possibilities in the work of compressed air in pumping water to great heights from shallow sumps by the Pohlé air-lift system. In order to show the detail of operations the illustration is spread out. In practice the several wells may be bunched together to occupy the smallest space in a mine shaft. It will be readily perceived that but one air pressure is needed, no more than sufficient to operate the highest lift in the multiple-stage system. The lesser lifts may be regulated by valves in the air branches to exactly meet the volume and pressure required for the lower lifts. Its air economy may balance the cost of a deep sump, but its efficiency is yet to be tested.

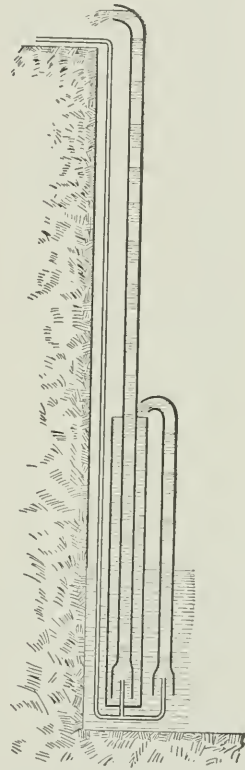


FIG. 504.—DUPLIX AIR LIFT.

THE AIR-LIFT PUMPING SYSTEM OF THE
PNEUMATIC ENGINEERING COMPANY,
NEW YORK CITY.

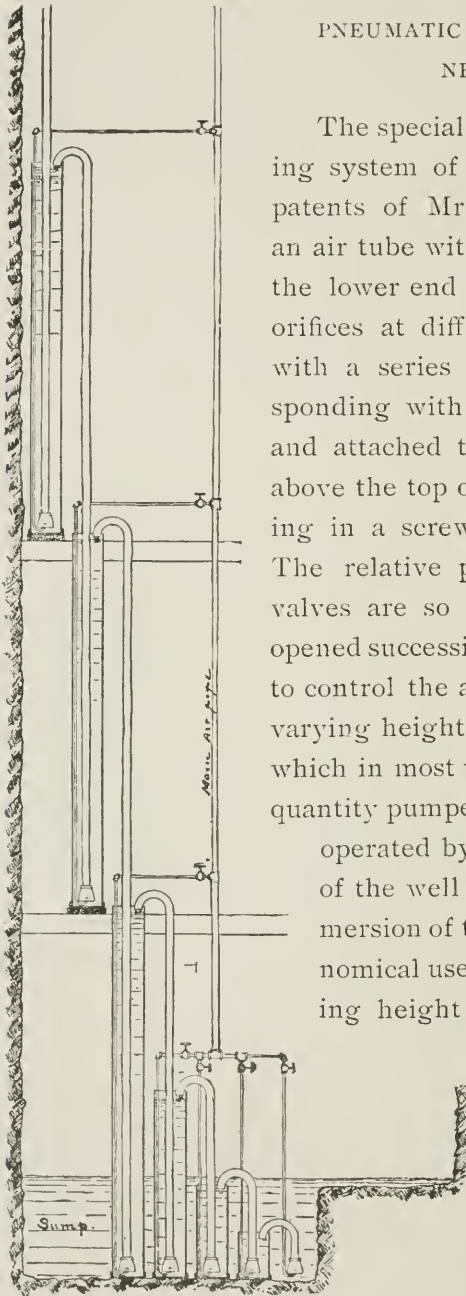


FIG. 505.—MULTIPLE STAGE AIR LIFT.

The special feature of the air-lift pumping system of this company is due to the patents of Mr. S. W. Titus, which claim an air tube within the well tube, closed at the lower end and perforated with lateral orifices at different points in its height with a series of cylindrical valves corresponding with the orifices, differentially, and attached to a central stem projecting above the top of the air pipe and terminating in a screw, yoke, and valve wheel. The relative positions of the orifices and valves are so arranged that they can be opened successively from the top downward to control the air pressure required for the varying heights of the water in the well, which in most wells varies greatly with the quantity pumped. By this device, which is operated by the valve wheel at the top of the well pipe, the best point of submersion of the air pipe for the most economical use of air required for the varying height of the water level in the well and the height to which the water is to be pumped, is obtained. The section to the left in Fig. 506 shows a double-tube well; the sections are self-explanatory.

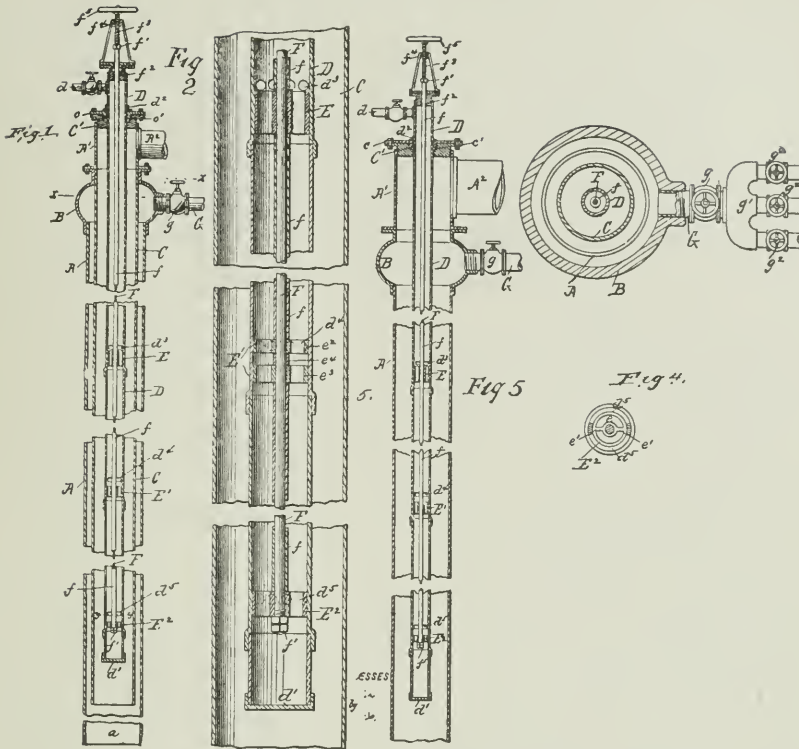


FIG. 506.—AIR-LIFT PUMP OF THE PNEUMATIC ENGINEERING COMPANY.



FIG. 507.—A LINE OF WELLS OPERATED BY COMPRESSED AIR.

Fig. 507 is a scenic view of a system of air-lift gang wells discharging into the funnels of an underground conduit having a gravity flow to a basin from which the water may be pumped to a high reservoir.

A direct system of pumping water by compressed air under the patents of Prof. E. G. Harris is operated by this company.

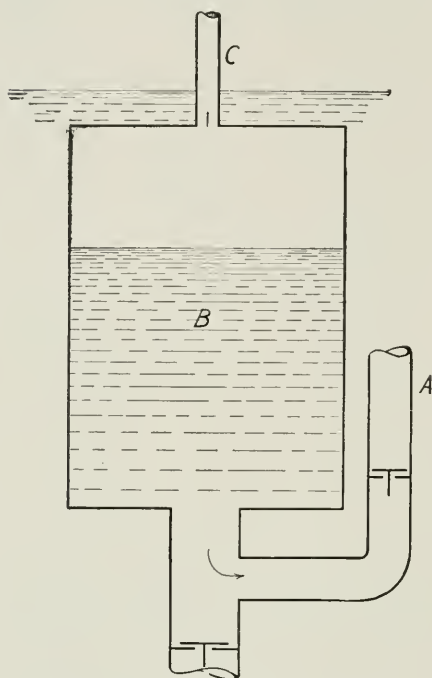


FIG. 508.—DIRECT-PRESSURE SYSTEM.

The name "direct air-pressure pump" is applied to that class of pumps in which the liquid is taken into an air-tight vessel and then driven out by the application of compressed air directly to the surface of the liquid. For instance, if the vessel *B* (Fig. 508) contains water, and air be forced in through the pipe *C*, the water will be driven out through the pipe *A*. The apparent simplicity of this operation, and the absence of costly cylinders, pistons, rods, valves, etc., have made it a popular

means of water supply with various modifications. This system is not a new one, having been patented by Upham in 1809, and the system in its duplex form was patented in England in 1865.

The apparent difficulty in the use of this system lies in the loss of power when the compressed air in *B*, after driving the water out of the vessel, is allowed to escape into the atmosphere, thus losing all the power that was required to compress the air. The percentage of this loss increases with the head against which the water is pumped, and is about 50 per cent when pumping to a height of 100 feet.

In the following system, the above difficulties are overcome to a degree that cannot be surpassed; for in it there are *no floats* and the air is *not allowed to escape*, being used over and over so that none of the work done on it is directly lost.

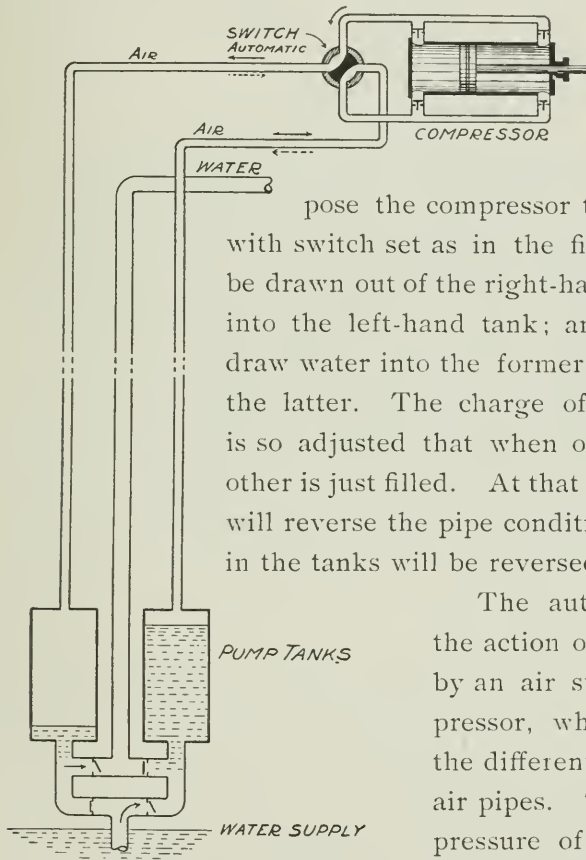


FIG. 509.—DUPLEX AUTOMATIC WATER LIFT.

Fig. 509 shows how the above conditions are attained. Suppose

the compressor to be in operation with switch set as in the figure; the air will be drawn out of the right-hand tank and forced into the left-hand tank; and in so doing will draw water into the former and force it out of the latter. The charge of air in the system is so adjusted that when one is emptied the other is just filled. At that moment the switch will reverse the pipe conditions so that action in the tanks will be reversed.

The automatic control of the action of the pump is made by an air switch at the compressor, which is thrown by the differential pressure in the air pipes. The change in the pressure of these pipes alternating between the hydrostatic

pressure in the air force pipe and the absolute pressure in the air suction pipe is equal to the head of water in the tank above the water level in the well. At the moment of the greatest difference in pressure in the air pipes, the automatic switch reverses the connections, and the compressor draws the air from the empty chamber and forces it into the full chamber. The compression and expansion nearly balance each other, and there is but little loss in power.

The same system, as shown in Fig. 510, may be operated as a two-stage or compound water lift by placing one of the chambers in the well or sump and discharging its water into a sump or open tank at a higher level. They may be operated alternately as before, and thus be made

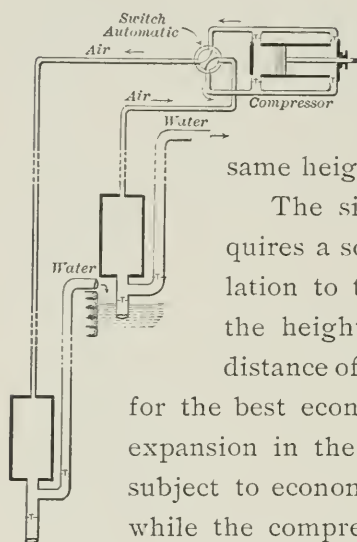


FIG. 510.—TWO-STAGE AIR-LIFT PUMP.

to raise one-half the volume of water to double the height, or raise one-half the volume to the same height with one-half the air pressure.

The size of air pipes in this system requires a somewhat complex adjustment in relation to the size of the water chambers and the height of the water lift, as well as the distance of the compressor from the chambers, for the best economy; the work of compression and expansion in the air pipes being an absolute loss subject to economical adjustment for least friction, while the compression and expansion in the displacement chambers are a necessary loss to meet the hydrostatic conditions of the height to which the water is raised.

Its efficiency is due to the well-balanced condition of the pumping plant, including the compressor, sizes and length of air and water pipes, that the friction may be a minimum for the quantity of water to be pumped. Under the best conditions, an efficiency of 65 per cent of the indicated work of the compressor may be expected at 75 pounds air pressure, pumping water to a possible height due to that pressure, and varies inversely with the height and pressure.

The principle of the direct air-lift pump with discharge of air at each stroke is illustrated in Fig. 512 by one of the earlier methods of operating the air valve by a float, which was placed on the outside of the chamber and connected with the top and bottom of the chamber by a flexible tube; so that the float, alternately filled with water or air by hydrostatic equilibrium

through the flexible tube connection, was raised at the moment of full discharge of water from the chamber, throwing the air

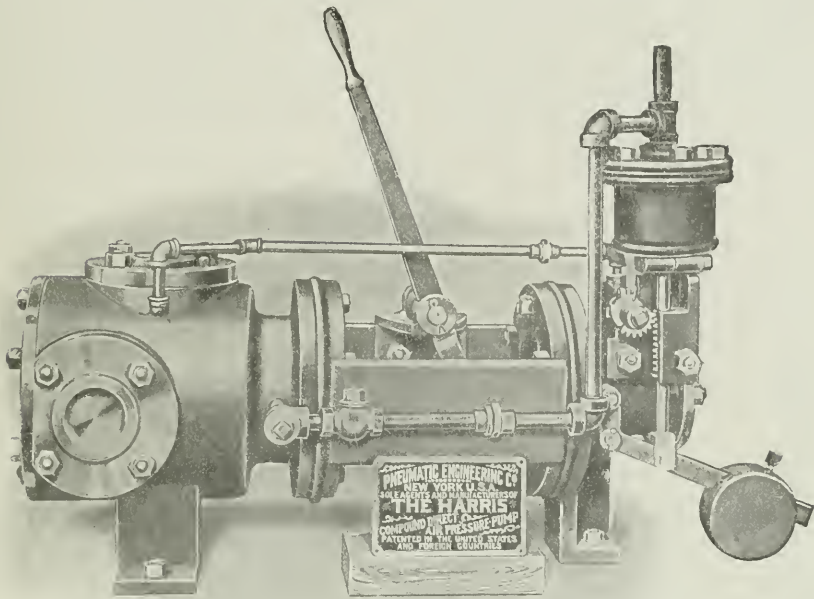


FIG. 511. THE AUTOMATIC SWITCH OF THE HARRIS SYSTEM.

valve open to the exhaust and closing the air inlet. The water rising in the chamber filled the float at its upper position, when it fell by its weight, fully opening the inlet air valve and closing the exhaust. A flap valve on the bottom of the chamber admitted the water by gravity. This system has been modified in various ways by rods directly connected to the air valve and a sliding float within the chamber, one form of which is illustrated in Fig. 513, in the Halsey pneumatic pump, which consists of a tank submerged in the water or other liquid to be

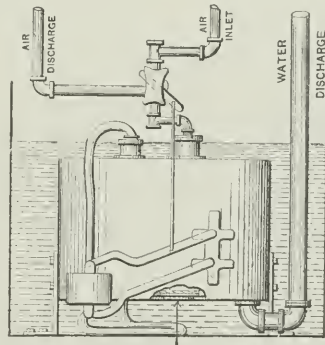


FIG. 512.—FLOAT-GOVERNED AIR-LIFT PUMP.

pumped. From the air valve contained in the top casting a rod descends through the tank, having a float upon it, this float being an inverted bucket of sheet metal. The water flows into the tank when the air exhaust is open, the inverted bucket riding on top of the water; and when full the bucket engages with

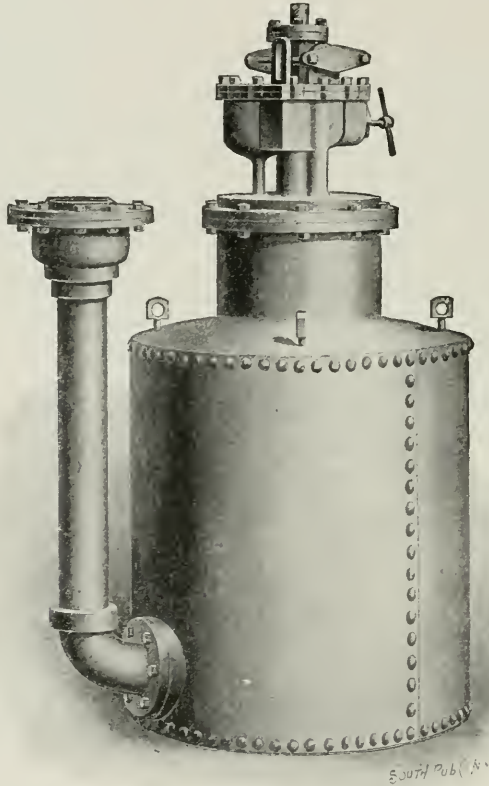


FIG. 513.—THE HALSEY DIRECT-AIR-PRESSURE PUMP.

a collar on the top of the rod lifting the same, opening the air valve and closing the exhaust. The air is thus admitted directly to the surface of the water and forces it out. As the water level descends the bucket at the lower end becomes uncovered; its weight pulls down the rod and reverses the valve, thereby discharging the air, when the operation is repeated. We should say that the rod described also operates a supple-

mentary valve which turns the air into one or the other end of the main valve-chest precisely like a common steam pump. It is plain that the machine is entirely automatic and extremely simple, and adapted to a very wide range of uses. It is part of the Pneumatic Engineering Company's pumping system.

In the Clayton patent lately issued, a sealed float rises and falls on a rod with stops to operate the air valve.

A combination of the direct-acting tank system and the Pohlé expansion air lift has been devised by Mr. Wheeler, by which the high-lift system may be utilized from a shallow sump by raising the water about one-half the height by direct pressure, then injecting air under the water column from the same air pipe used for the direct lift, and thus doubling its elevation. In Fig. 514 is shown a sectional elevation of this system, in which *A* is the direct pressure or displacement chamber, from which the water is raised to a height at *C*; air is injected at *B*, and by its lifting and expanding action completes the lift; the pressure in the chamber *A* being equivalent to the deep immersion required in the Pohlé system. This system, as shown in the figure, is alternating, and evidently could not run constantly with one chamber; but by making a double-chambered direct lift as in Fig. 518, and connecting the air pipe to the water column direct from the pressure side of the air compressor, and using the air switch only on the direct-lift pipes, a continuous flow would be obtained.

The efficiency of the Wheeler pneumatic pump just described compares very favorably with any of the other methods of pumping by air pressure. In a series of tests made by Mr. H.

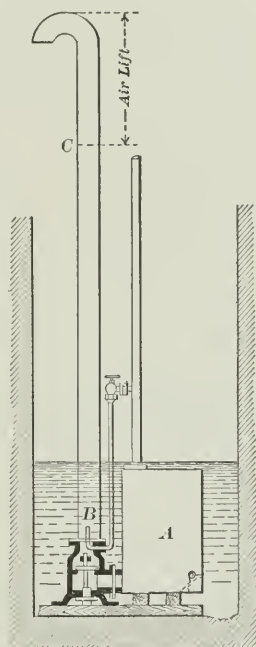


FIG. 514. — COMBINED AIR-LIFT PUMP.

C. Behr, published in *Compressed Air*, the computed efficiencies under varying conditions of air pressure of from 19 to 41 pounds per square inch for a lift of 105 feet from a shallow sump, as shown in Fig. 514, were from 24 to 48 per cent of the least work needed from the compressor, or from 17 to 30 per cent including the efficiency of the compressor.

COMPRESSED-AIR PUMPS OF THE MERRILL MANUFACTURING COMPANY, NEW YORK CITY.

We illustrate in the following figures the automatic compressed-air system of the above-named company, who are operating under the patents of Mr. F. H. Merrill. By this system air may be compressed at any available distance from a well or water supply, and perform its whole duty, save friction, in

pumping water to any required height or into horizontal mains to distant reservoirs.

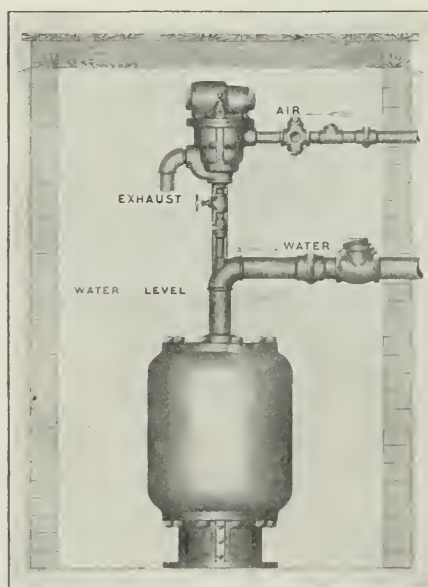


FIG. 515.—SINGLE-ACTING PUMP.

The apparatus consists of one or two water chambers, adapted to be submerged at the source of water supply, and an automatic air valve located above the water and connected with the chambers by one or two air pipes. The automatic air valve directs compressed air to and from the water chambers, from which the water is al-

ternately discharged by the direct action or displacement of the compressed air, without the intervention of pistons or other complicated mechanism.

By the duplex arrangement of chambers a perfectly steady discharge is obtained.

The automatic air valve (Fig. 516) is by far the most important part of the apparatus. This device is a remarkably simple and ingenious mechanism, self-contained and certain in its action. It is actuated solely by compressed air applied on differential surfaces, and is entirely independent of the water chambers. The valve head contains a double-disc differential air valve, which is operated in one direction by compressed air through

FIG. 516.—AUTOMATIC AIR-VALVE HEAD.

a small valve port opened by a water float in the under section of the valve head, and in the opposite direction by a spring. The water enters by a pipe connection with the main discharge pipe and is released by the air when the water in the pump chamber falls to the discharge valve by the uncovering of a supplementary pipe connected with the float chamber. The throw of the differential valve operates a piston valve to change the flow of compressed air alternately from one chamber to the other, and also alternates the exhaust.

The single chambers are made for capacities of 25 and 50 gallons per minute.

In Fig. 517 is shown the internal construction of the water chamber with the inlet and discharge water valves.

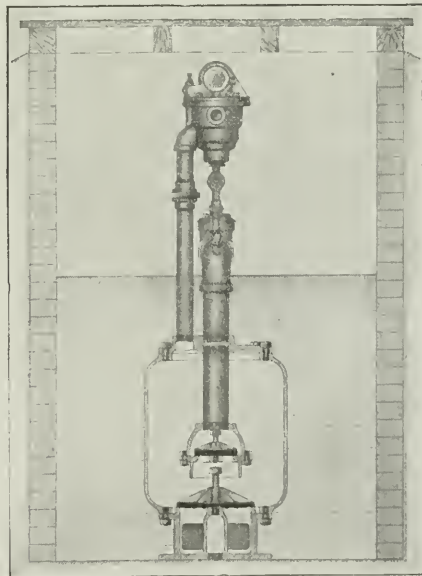


FIG. 517.--SECTION, WATER VALVES.

In Fig. 518 is represented the larger size of a duplex direct-acting air pump having a capacity of from 200 to 350 gallons per minute.

With this class of water lifts it is not necessary to place the operating valve mechanism near the water chambers as repre-

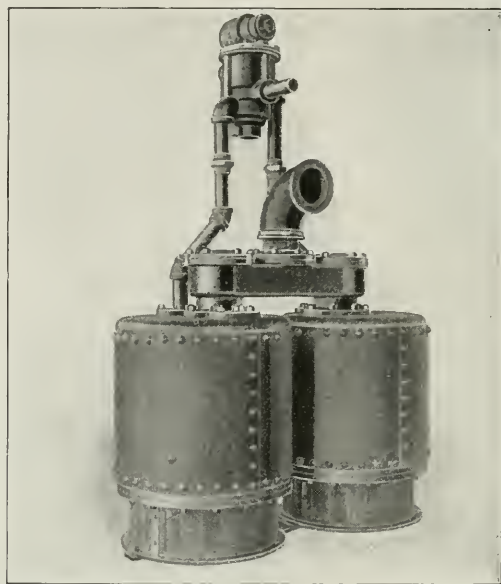


FIG. 518. — THE DOUBLE-CHAMBERED PUMP.

sented in the figures, but at any convenient location at the top of the well where it can be easily inspected; then there will not be less efficiency of the pump than is due to the volume of the air in the connecting pipes, between the valve and chamber.

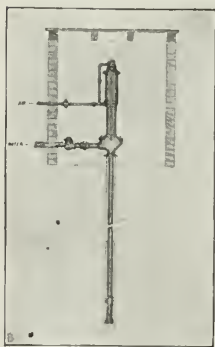


FIG. 519 — DIFFERENTIAL PISTON PUMP.

A differential piston air-lift pump (Fig. 519) is made by this company, adapted for light duty and domestic service, and is designed for pumping from driven wells or any place where a displacement pump chamber cannot be inserted or submerged.

It consists of two brass differential cylinders, having connected pliable packed

differential pistons, and an air-pressure controlling valve in the head of the larger cylinder, actuated by the pistons at the extreme end of their strokes.

This little pump will fill the requirements of many light duty cases, using compressed air furnished by an air compressor located any distance away, driven by any available power—belt, steam, electricity, gas, or oil. It is suitable for any suction up to 15 feet and for 50-feet lift.

In Fig. 520 is shown the combination inductor and displacement pump, for use in bored wells, in which the induced lift on the principle of the Pohlé air lift raises the water to a displacement chamber in a pit at the surface, from which it is raised to the required height by direct air pressure.

In Fig. 521 is shown a section of a gang system of air-lift wells with central displacement pump.

In Fig. 522 is shown a Merrill water-pumping system for service where it is necessary that the valve mechanism or working parts be placed some distance from and above the water chambers, as in the case of rivers where the rise and fall of water are great, and where it is desired to have the controlling valve above high water, and accessible at all times.

By this system of arranging the location of the air valve above and at a distance from the location of the well or intake, and thus facilitating a pure water supply for public and private use by locating the wells in the filter sands of streams and water-courses with the air valves on the bank and an air-compressing station at any convenient distance, a valuable water-supply service may be made available at all times and under any condition of flood that would otherwise derange the old

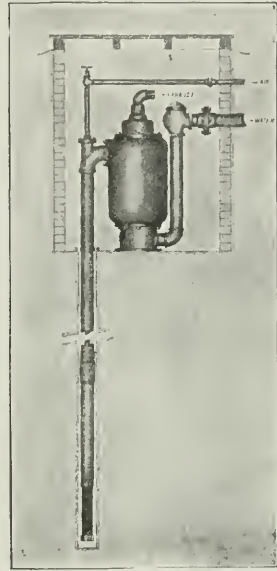


FIG. 520.—COMBINATION PUMP.

systems of water supply from rivers. The only precaution necessary would be to build the well curb above the flood line, or cover the well with sand and carry the exhaust pipe up the bank, or to a safe place out of flood-water range. In this manner the neglected and scanty water supply of towns and factories may be reinforced with the pure and filtered element so essential to life and prosperity.

Air pressure is used for elevating milk in dairies and for aerating milk. For elevating, the milk is poured into large

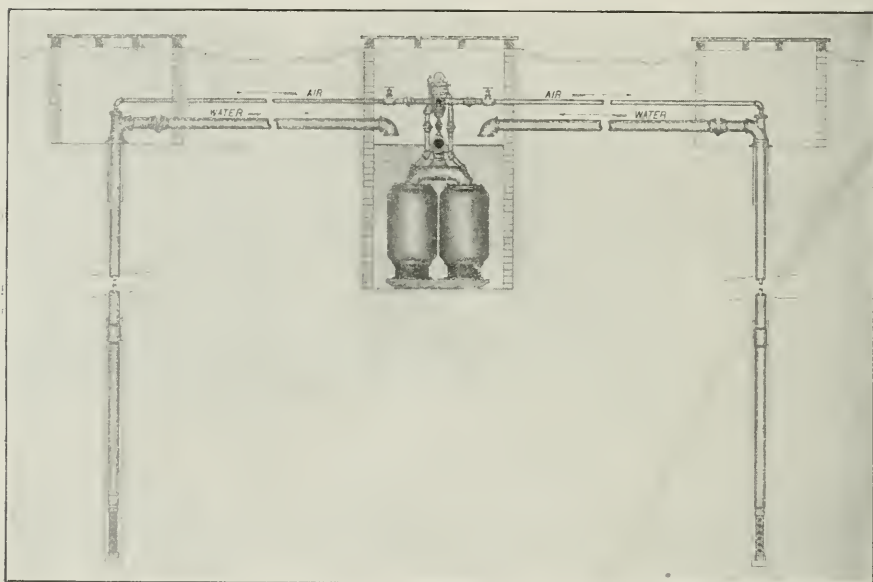


FIG. 521.—THE GANG SYSTEM OF BORED OR DRIVEN WELLS.

In combination with the direct air-pressure lift. By this method a settling basin will gather the sand from the bored wells, and the direct displacement pump will be free to pump clear water.

cans, the top closed and connected with an air pump. A pipe from the bottom of the can conveys the milk under air pressure to any required height or distance.

Color liquids in dye houses which are destructive to pumps, or are injured by contact with the metals of pumps, are elevated or discharged at various points through pipes suitable for the coloring fluids, by direct air pressure.

In chemical works the same system of transfer of acids is used.

The manufacture of sulphuric acid is a compressed-air process in which the large condensing chambers are dispensed with and the process is made more direct and compact. The sulphur is burned under air pressure in an air-tight furnace, and by the

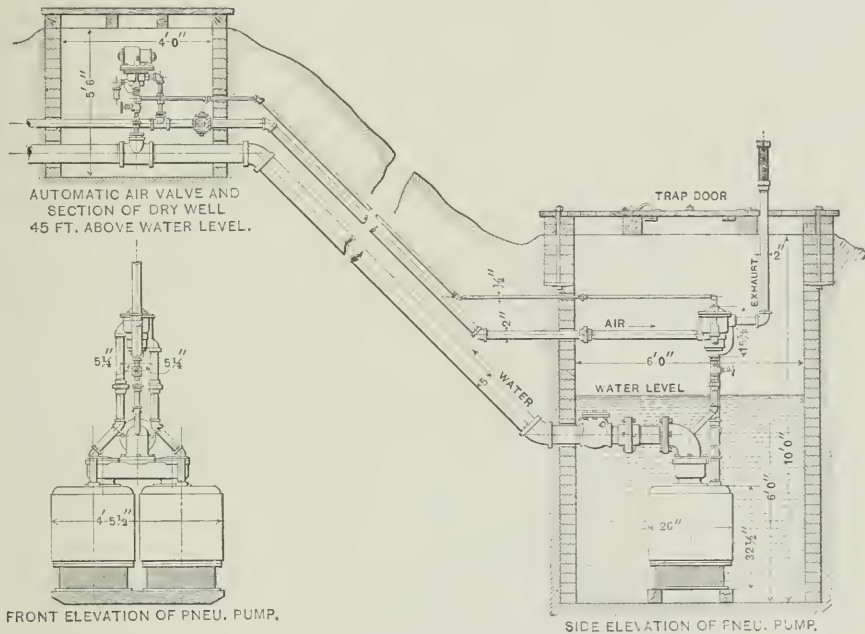


FIG. 522.—THE MERRILL PNEUMATIC PUMP.

Direct acting, with elevated air valves.

same pressure the products of combustion are forced through pipes beneath water in a closed tank, rising in bubbles, and so on through a series of tanks, until the entire acid product is absorbed.

ECONOMY OF COMPRESSED AIR IN PUMPING.

Fig. 523 represents what has been termed the endless chain of pneumatic power, by which a volume of air is compressed, transmitted to a pump or motor, does work, is exhausted into a return pipe, and retransmitted to a low-pressure receiver at a

low temperature, and again compressed to the proper working pressure for another round in this cycle of air work. It has been in use in California for several years with success for pumping and drilling, and is known there as the "Cummings process" or system.

The economy of this system is most apparent in eliminating frost at the exhaust and the conservation of heat. The mois-

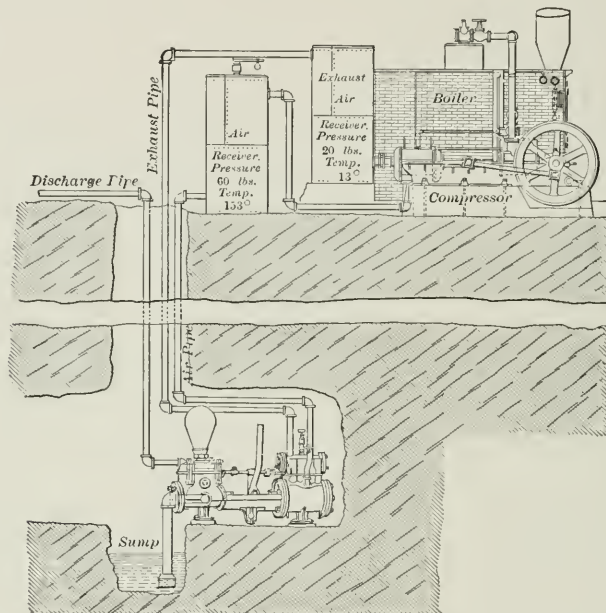


FIG. 523. THE ENDLESS CHAIN IN COMPRESSED-AIR WORK.

ture in the air is soon condensed and deposited in the low-pressure cold-air receiver, when the system becomes a dry-air one, and may be operated as a dense-air system by which the adiabatic losses are lessened by operating on the greater curve of heat expansion and contraction due to higher pressures as well as the less differentiation of volumes at the higher pressures. This singular property of compressed air is graphically illustrated in the diagram (Fig. 45). It is also in use in the Allan dense-air refrigerating machine.

The economies of this system, due to working pumps and

drills or motors that carry full pressure nearly to the full stroke, have been worked out by Mr. A. E. Shodsko, who has found an efficiency of .69 with working pressures of 200 and 100 pounds in the two pipes, as against .33 in the single-pipe system, as ordinarily used, as between the compressor and motor. With reheating the efficiency is increased in this system to a possible 85 per cent. In ordinary pressures used in mining machinery, say up to 90 pounds, and exhausting into the return pipe at 30 pounds pressure, the continued operation will work under a temperature cycle of 200° F., while in the single-pipe system with open exhaust the working cycle is about 300° F. under the same operative pressure.

The claim for efficiency and practicability for this system seems to have been criticised by assuming that the motor, pump, or drill must be operated at full pressure for the full stroke; but this claim is not reasonable, for the possibilities of expansion between the initial pressure in the flow pipe and the pressure in the return pipe only involves the air friction in the two pipes, leaving a considerable margin for expansion economy in motors; but this principle cannot be applied to rock drills and hoisting engines further than their fixed cut-off.

COMPRESSED AIR FOR LIFTING SEWAGE.

The Shone system as used in England is illustrated in a vertical view of the air lift in Fig. 524 and a plan in Fig. 525, which represents the sewerage system in the city of Norwich, England. The old works were subject to floods in the lower part of the city; by the apparatus shown in the illustration the old sewers were intercepted at five points near the river, and water lifts by direct air pressure were located to lift the sewage from 15 to 21 feet in different localities to a main outfall sewer that discharged at a distant pumping station, from which it is pumped to a sewage farm. A pair of turbine wheels at the dam above the town operate the compressors at 18 pounds pressure, which dis-

charge 650 cubic feet free air per minute into two large receivers, from which the compressed air is distributed through

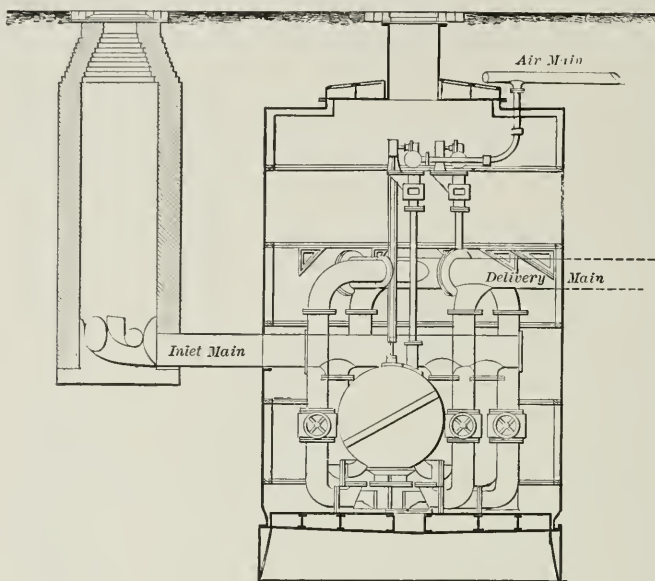


FIG. 524.—ELEVATION OF SEWAGE LIFT.

underground mains to the different lift stations. Each station is provided with two air-lift chambers with floats and trip valves or rods to operate the air valves. The ejector chambers vary

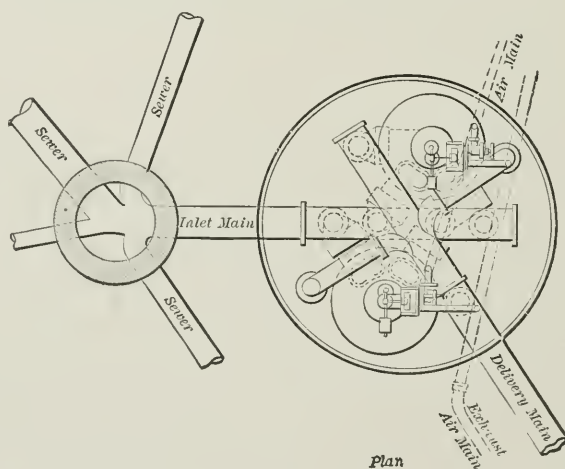


FIG. 525.—PLAN OF SEWAGE LIFT.

in size at the different stations to meet the variation in sewage flow from the districts converging at each station, ranging in cubic contents from 300 to 2,000 gallons.

The automatic pneumatic cesspool drainage is extensively in use in the United States. Its convenience and value from a sanitary point of view cannot be overrated. A simple form of this device is in operation at La Crosse, Wis., to clear the pits of a round-house; consisting of a large tank in a catch-basin, in which a float slides upon a rod between stops that opens a three-way valve in an air-pressure pipe which discharges the water to a higher level sewer, the water flowing into the tank by gravity through a flap valve on the release of the air pressure through the action of the float and valve.

AERATION OF WATER BY COMPRESSED AIR.

It is well known now, among hydraulic engineers, that an ample aeration of water in tanks and reservoirs will prevent stagnation, check the growth of algæ, remove the disagreeable odor from decomposing vegetable matter, and deposit the salts of iron that sometimes pervade waters from iron soils or that have traversed long lines of iron pipe. Fig. 526 represents the pipe plan for aerating a tank 62 feet in diameter, 59 feet high, holding 1,300,000 gallons, at Brockton, Mass.

In the bottom of the tank are three 2-inch galvanized iron pipes which radiate from a point near the side as shown. The centre arm is 56 feet long, and the two side arms 47 feet. Spreading out from these pipes are thirty-nine brass tubes one-quarter inch in diameter, except five long branches from the centre arm, which are three-eighths inch in size.

The small pipes are perforated at distances of 3 feet with $\frac{1}{7}$ -inch holes, and are supported on iron chairs which hold them clear of the bottom. The 2-inch pipes are carried through the supply pipe from the pump, and furnished with valves to control the flow of air. They are finally connected with a $2\frac{1}{2}$ -inch

pipe from the pumping station, which is provided with a check valve to prevent water from going to the pump. The air is supplied by a $7\frac{1}{2} \times 9 \times 9$ inch Clayton duplex compressor, furnishing 172,000 cubic feet of air in twenty-four hours. The air is forced directly into the tank, no receiver being used. By this means the water is thoroughly agitated and aerated, doing away with its former odors and taste.

Another method of aeration of water is by pumping air directly into the main between the intake and the reservoir, and into the delivery main from a reservoir.

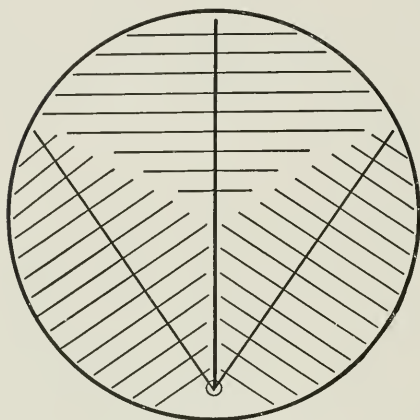


FIG. 526.—WATER-TANK AERATION.

In another case, in order to improve a supply drawn from a lake in which algæ had given some trouble, a 12-inch pipe was laid from the gate house at the lake for a distance of 350 feet to within 50 feet of the lowest part of the main. At this point a small Clayton compressor, driven by a 10-inch

double-discharge turbine, was set up. This plant required 259,000 gallons of water in twenty-four hours to force 82,250 gallons of air into the 200,000 gallons of water supplied to the town from the lake. When the water was turned on to the wheel, the air was forced into the main against the flow in the pipe and rose toward the lake, coming up through the gate house in great volumes and agitating the water with considerable violence, so that it immediately lost its taste and odor. The pressure of the air as delivered from the compressor was 20 pounds per square inch. In this connection, attention is called to the aerating plant at Charleston, S. C., where equal satisfaction has followed the adoption of this method of purification. Every practical superintendent and engineer who has

had any extended experience with aeration seems to favor it, as far as we have been able to learn. As the subject now stands, it is pretty generally admitted that aeration will prevent stagnation, check the growth of algæ, remove disagreeable gases, and deposit the salts of iron that sometimes occur in a ground water, although it has yet to be proved that it will hasten the oxidation of organic matter.

Water in its natural state is never found chemically pure; matter more or less foreign is identified with it and detected under the test of the chemist. Nevertheless, waters thus found are fit for human consumption, and, taken from nature's laboratory, are pure enough for general use.

The methods adopted for purifying water are oxidation or aeration and filtration. Nature herself practises and carries on successfully the process of purification. When her administration is interfered with by man's construction of dams and reservoirs to confine her waters, it then becomes necessary for him by mechanical means to imitate her example. In this attempt he must recognize her laws. Oxidation or aeration is one of nature's processes carried on successfully for the purification of water. The oxygen is dissolved in the water, coming in contact with whatever organic matter may be associated with the water, changing it into nitrites and carbonic acid. The greater the agitation of the waters, the greater the beneficial changes thus wrought.

Cascades, fountains, the introduction of air to conduits, artificial falls, thin films of water passing over large surfaces—in fact, any device that will permit the air to mingle with the waters—give new life to the waters and death to organisms. The plan adopted by the Utica (N. Y.) Water Company is on the fountain principle, discharging the water under pressure through a series of pipes, the aggregate areas presumably equal to the main discharge pipe, and into a shallow basin. The greater the pressure the greater the height the waters are elevated by their several columns, giving proportionately time

for the action of the air on the ascending and descending waters. It occurs to one's mind, however, that the quantity of water thus treated should not be in excess of the daily amount used, that each day's supply of water should be fresh. This mode of purification of water will require treating reservoirs of shallow depth and surface area equal to requirements.

A similar plan to the Utica plant is the one at Fresh Pond, adjacent to the Stony-brook reservoir, at Cambridge, Mass.; different in that four outlets of discharge are in use, and throwing the water into the air 40 feet above its outlet.

THE PNEUMATIC CYANIDE PROCESS FOR THE EXTRACTION OF GOLD.

The features of the "pneumatic" process are so easily understood that it does not require an expert or a thorough chemist to appreciate them, for every mining man has had more or less experience with compressed air, and most of them know something about the cyanide process and understand that oxygen is absolutely necessary in a solution of cyanide of potassium in order to form a new compound, cyanogen, which is the true

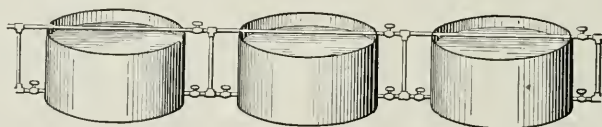


FIG. 527 — SERIES OF LEACHING VATS, OR TANKS, FITTED WITH PIPES AND VALVES FOR THE INTRODUCTION AND CONTROL OF THE COMPRESSED AIR.

solvent of the gold. They know also that agitation hastens the process of dissolving and extracting the gold values during the leaching process, because agitation, or stirring, enables the oxygen of the air to reach the solution more rapidly to form cyanogen and also to bring the ore and solution into more intimate contact, and does in a few hours what it takes days to do if the ore and solution remain unmoved in the leaching vats.

Many attempts have been made to stir or agitate the mass

of leaching ore by machinery; but the great costs of power, expensive construction, breakage of parts, etc., have caused them to be abandoned, and mill owners have gone back to the old slow process of letting the ore stand for days in the leaching vats because there was no practical and cheap way of agitating



FIG. 528.—SECTION THROUGH THE LEACHING VATS.

Showing the air pipes under the perforated bottom and the double trap-door in the bottom for discharging the leached refuse.

them, or of getting the oxygen through the solution, except by the slow absorption from the atmosphere.

Just at this time, when it seemed as if improvement in the cyanide process was at a standstill, the "pneumatic" process comes forward with a method so simple and so effective that it is a wonder that it was not thought of sooner.

It is simply the introduction of strong currents of compressed air into the bottom of the leaching vats, which force their way upward bubbling and boiling through the mass of crushed ores and cyanide solution, and thus furnish both the oxygen and the agitation needed for the rapid and thorough extraction of the gold. This method of forcing the air through the leaching ores can be readily understood by means of the cuts shown. The air pressure required is small; no more than to overcome the hydrostatic pressure of the liquid and keep the air bubbling like boiling water. Reheating the air tends to warm the liquid and to facilitate the work. It amply pays for reheating the air.

WOOD VULCANIZING.

The process of vulcanizing wood by the Haskins system is about as follows: Large iron or steel tanks are arranged horizontally and of sufficient size to admit the charge of wood required to be vulcanized.

Coils of pipe are placed inside the tanks for the purpose of heating the air to the desired temperature of about 285° to 300° F. The heating is usually done by steam. The wood is placed inside the pipe-line tanks and steam is turned on until the interior is heated to about 200° F. Then the openings are closed and compressed air is admitted up to 150 or 200 pounds pressure. The air is kept circulating around the wood at an average heat, the desired temperature being 285° to 300° F. for eight or ten hours. The circulation is accomplished by means of a circulating engine which takes the air out of the vulcanizing tank, passes it through a reheater and back to the tank. This process prepares the wood in such a way that it will last almost indefinitely.

AGING OF LIQUORS.

The purifying of alcoholic liquors is accomplished by compressed air through the Cushing process, which has been in vogue for many years. The liquor is placed in receptacles for the purpose, and air, after it has been washed and purified by Professor Tyndall's well-known method, is compressed and forced through perforated pipes entering the liquor in minute streams. The liquid is violently agitated and the air permeates every portion of it. The air being warm oxidizes the fusel oil and at the same time volatilizes and expels into the open air the light poisonous ethers, leaving the liquors thoroughly pure and free from aldehydes. It is claimed that by this process new liquor for medicinal purposes is made practically as good as old, and that the drinking of liquor treated thus does not cause stupefaction, headaches, and other disagreeable results.

Chapter XXXIII.

REFRIGERATION

REFRIGERATION.

REFRIGERATION BY THE VACUUM SYSTEM.

THIS is generally known as the vacuum process, for as the refrigerating agent itself is rejected, the only agent of a sufficiently inexpensive character to be employed is water, and this, owing to its high boiling-point, requires the maintenance of a high degree of vacuum in order to produce ebullition at the proper temperature. The vapor tensions of water at temperatures up to boiling-point at atmospheric pressure are given in Table II., from which it will be seen that at 32° F. the tension is only 0.089 pounds per square inch. In ice-making, therefore, a degree of vacuum must be maintained at least as high as this. The earliest machine of this kind appears to have been made in 1755 by Dr. Cullen, who produced the vacuum by means of an air pump. In 1810 Leslie, combining with the air pump a vessel containing strong sulphuric acid, for absorbing the vapor from the air drawn over, and so assisting the pump, succeeded in producing an apparatus by means of which from one to one and one-half pounds of ice could be made in a single operation. Vallance and Kingsford followed later, but without practical results; and Carré many years afterward embodied the same principle in a machine for cooling and for making small quantities of ice, chiefly for domestic purposes. His machine, which is still sometimes used, consists of a small vertical vacuum pump worked by hand, either by a lever or by a crank, which exhausts the air from the carafe or decanter containing the water or liquid to be frozen or cooled. Between the pump and the water vessel is a lead cylinder, three-fourths full of sulphuric acid, over which the air, and with it the vapor given off from the liquid, is caused to pass on its way to the pump. The vacuum

thus produced causes a rapid evaporation, which quickly lowers the temperature of the water; and if the action is prolonged for about four or five minutes, the water becomes frozen into a block of porous, opaque ice. The charge of acid is about four and one-half pints, and it is said that from fifty to sixty carafes of about a pint each can be frozen with one charge. So long as the joints are all tight, and the pump is in good order, this apparatus works well; but in practice it has been found troublesome and unreliable, and consequently has never come into anything like general use.

In 1878 Franz Windhausen, of Berlin, Germany, brought out a compound vacuum pump for producing ice direct from water, on a large scale, without the employment of sulphuric acid; and also an arrangement in which sulphuric acid could be used, the acid being cooled by water during its absorption of the vapor, and afterward concentrated, so that a fresh supply was rendered unnecessary. This apparatus was improved on in 1880; and in 1881 a machine nominally capable of producing 15 tons of ice per twenty-four hours was put to work experimentally at the Aylesbury Dairy at Bayswater, England. It consists of six slightly tapered, ice-forming vessels of cast iron, of circular cross section, closed at their bottom ends by hinged doors with air-tight joints, into which water is allowed to flow through suitable nozzles, the cylinders being steam-jacketed in order to allow the ice to be readily discharged. The upper parts of these vessels communicate with the pump through a long horizontal iron vessel of circular section containing sulphuric acid, which, when the machine is in operation, is kept in continual agitation by means of revolving arms. The acid vessel is surrounded with cold water, which carries off most of the heat liberated during the absorption of the vapor. The pump has two cylinders, one double-acting of large size, and a smaller single-acting one. The capacities of these cylinders per revolution are as 62 to 1. The air and whatever vapor has passed the acid are drawn into the large pump, which partially

compresses and delivers them into a condenser. Here part of the vapor is condensed by the action of cold water, the remainder passing along with the air to the second pump, where they are compressed up to atmospheric tension and discharged. The advantage gained by the use of a compound pump is due to the action of the intermediate condenser and to the compression being performed in two stages, by which the losses from the clearance spaces in the large pump are rendered much less than they would be if compression to atmospheric pressure were accomplished in a single operation. The effect of the pump is said to be such that a vacuum of half a millimetre of mercury, or about 0.0097 pound per square inch, can be continuously maintained; though in actual work about $2\frac{1}{2}$ millimetres, or 0.0484 pound per square inch, is as low as is necessary. The concentration of the acid is effected in a lead-lined vessel, in which is a coil of lead piping heated by steam, the pressure in the vessel being kept down by means of an ordinary air pump. No acid pump is needed, as the transfer from one vessel to another is effected by the pressure of the atmosphere. The comparatively cool weak acid on its way to the concentrator is heated in an interchanger by the strong acid returning from the concentrator. Six blocks of ice, each weighing about 560 pounds, are formed in about twenty minutes after starting. The charge of acid is said to serve for three makings of ice, after which it becomes too weak, and requires to be concentrated.

The water being admitted into the ice-forming vessels in fine streams offers a large surface for evaporation, and is almost immediately converted into small globules of ice, which fall to the bottom and become cemented together by the freezing of a certain quantity of water that collects there. This water being in a violent state of ebullition, the ice so formed is not solid, but contains spaces or blow-holes, which, as soon as the block is discharged from the vessel, become filled with air and cause opacity. Several attempts have been made to produce

transparent ice by the direct vacuum process, but so far without success. Distilled water, or water deprived of air, has been tried, and hydraulic pressure has been used for compressing the porous opaque blocks, but neither plan has been found practicable commercially. It would appear that the only way to make clear ice by the vacuum process is by forming it in moulds, subjected externally to the action of brine previously cooled by the evaporation of a portion of its water. The cost in this case would necessarily be greater; but the ice would be solid and transparent, and would consequently have a higher commercial value. The latent heat of liquefaction of water being 142.6° F., the total heat to be abstracted in order to produce 1 ton of ice from 1 ton of water at 60° F. is 382,144 F. pound units. Taking the latent heat of vaporization of water at 32° F. to be 1,091.7, it is obvious that 350 pounds must be evaporated to make the ton of ice. But in addition the sensible heat of evaporated water, which entering at 60° would leave at about 32° , would have to be taken off; and this would require the evaporation of about $9\frac{1}{4}$ pounds more, making a total of about 360 pounds, without allowance for loss by heat entering from without, which would be considerable. The total water actually used is given by Mr. Piper at 12 tons per ton of ice, including the quantity required for cooling purposes. The fuel consumption is stated to be 180 pounds of coal per ton of ice; but a much larger quantity is actually required. It is consumed in generating steam for driving the vacuum pump and the concentrator air pump, and for evaporating the water absorbed by the acid. According to Dr. Hopkinson, the cost of making 1 ton of opaque ice is 4s. (about \$1); experience has shown that a much higher cost is required to cover the necessary expenses for repairs and maintenance. Windhausen's machine has not met with any extended application, owing no doubt to the opaque and porous condition of the ice produced by it, and to the large and cumbersome nature of the plant, which must doubtless require great care and supervision in working.

A vacuum apparatus for refrigerating liquids by their own partial evaporation, and for making ice, was brought out in 1878 by James Harrison in England. Its chief feature is the revolving cylinder or pump, which affords a simple and efficient means of exhausting large volumes of vapor of low tension, without incurring the loss from friction of ordinary piston-packings, and the trouble of keeping them tight and in good working order, while at the same time the first cost is much reduced. The pump consists of a hollow iron cylinder, revolving on a horizontal axis, and divided into compartments by longitudinal partitions of L section. It is partially filled with a non-evaporable liquid, or one which evaporates only at a temperature considerably in excess of that at which the refrigerating liquid is evaporated, and which is also chemically neutral to the vapor that is brought in contact with it. In practice, oil is the liquid used. The refrigerating or ice-making vessels, of any convenient form, are connected by a pipe with one end of a fixed hollow axle on which the cylinder revolves; and inside the cylinder another pipe rises up above the level of the liquid, the longitudinal partitions being stopped short at one end to enable this to be done. The compartments move round mouth downward, carrying with them the vapor with which they are charged, and compressing it to an extent measured by the distance they dip below the surface of the liquid; until, when the lowest position is approached, the compressed vapor is liberated, and rises into a fixed hood near the centre, in communication with a second hollow axle at the opposite end of the cylinder to that at which the vapor enters. Through this second axle the compressed vapor passes to a surface-evaporative condenser, in which it is partly condensed by the combined action of direct cooling and the partial evaporation of water trickling over the surface; the water of condensation, together with any air, is then compressed to the tension of the atmosphere by a small pump, and discharged. By this process it is expected to produce opaque ice on a large scale at a cost of

about 25 cents per ton. The fuel consumption will certainly be very small, because friction, which is a large item in the Windhausen apparatus, is here to a large extent eliminated. There would also be a saving of all the fuel used in concentrating the acid, and of much of the water required for cooling purposes, besides a reduction in the first cost of the plant and in the expense of maintenance.

Although for nearly a half-century much attention has been given to the subject of cooling and refrigeration by the vacuum process, it has not proved a commercial success; it is still feasible for experimental work, and claims a space in the history of air work.

COMPRESSED-AIR REFRIGERATION.

THE EARLIEST ICE MACHINE.

The earliest known appliance for making ice by compressed air seems to have been invented and put into actual practice by Dr. John Gorrie, of New Orleans, La., whose patent dates May 6th, 1851, although ice was actually made in his machine at Apalachicola, Fla., in the summer of 1850.

The machine consisted in its essential operating parts of an air-compressing cylinder and piston operated from a crank shaft by connecting rods.

A small injection pump operated from a cam on the main shaft was so adjusted as to inject a small spray of cold water into the cylinder during the latter part of compression at each stroke of the piston, thus being the leading practical application of the injection system for cooling the air during compression; the compressed air and injected water being driven together through the exit valves and through a coil of pipe immersed in a tub of cold water, to the receiver, from which the injected and condensed water was drawn off through a waste cock at the bottom.

On the same platform and connected with a crank on the

main shaft, was located the expansion cylinder with its piston and connecting rods.

The size of the expansion cylinder was made somewhat smaller than the compressor cylinder, to compensate for the decreased volume of air due to the difference between adiabatic

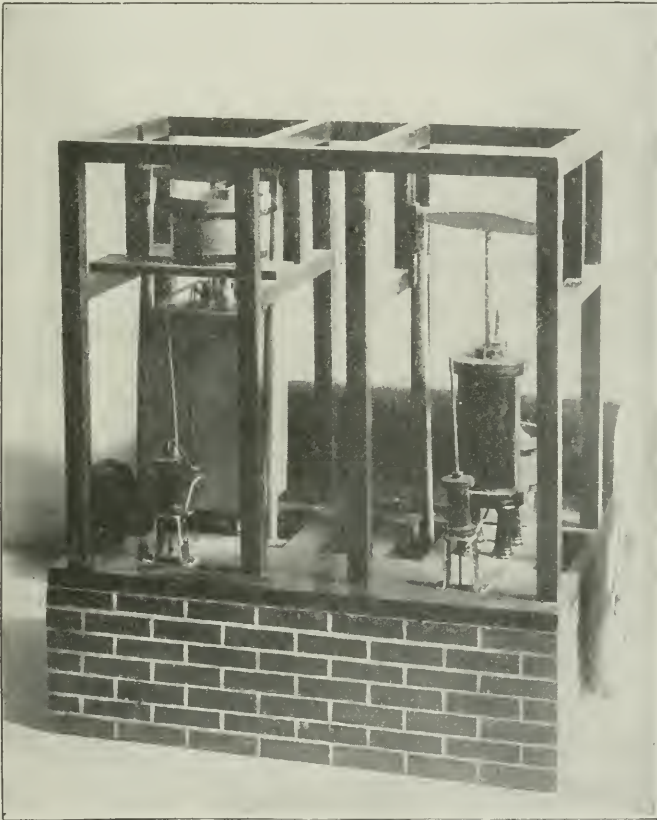


FIG. 329 THE GORRIE ICE MACHINE.

and isothermal values in compression and expansion for both cylinders.

The expansion cylinder was also provided with an independent injection pump operated from a cam on the main shaft by which an injection of a non-freezing liquid (brine) was made, which, by the convection of its heat to the cold air, becomes a

cooling medium, and was carried with the cold air through the exit valves and connecting pipe into the cold reservoir surrounding the cylinder.

The expansion cylinder was enclosed in a brine jacket with outlets for the cold exhaust and injection, through pipes terminating in the brine vat, for the purpose of utilizing the refrigerating effect of the expanded air for its full value; the free air, finally permeating the ice-making chamber above, and an outer insulating case surrounding the brine tank and expansion cylinder, made its exit through a coil in an insulated tank for cooling the water to be frozen, which was drawn from the cooling tank into the freezing cans of the form much in the style as now used, and placed in the cold brine tank for the freezing operation.

It may be seen from the amply illustrated description in the patent specifications, and from the testimony of persons that

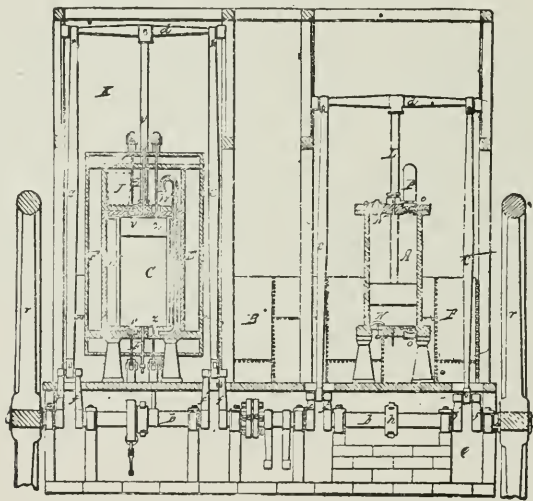


FIG. 530.—FRONT ELEVATION, ICE MACHINE.

saw the apparatus, that Dr. Gorrie had conceived and put into practice a device almost perfect in principle for refrigeration by compressed air at least a score of years before it became a commercial factor in any form.

The idea of using the terminal exhaust for cooling the water to be frozen to near the freezing-point was a most important one in the matter of economy.

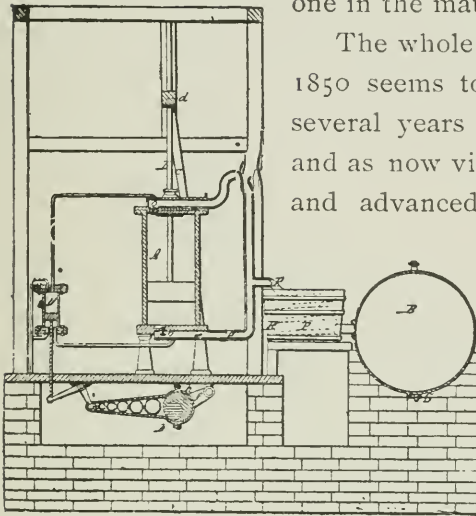


FIG. 531.—SIDE ELEVATION, ICE MACHINE.

A, The air-compressing cylinder; *B*, receiver or compressed-air tank; *R*, cooling tank with air-pipe coil *P*; *D*, injection pump for compressor spray, operated by cam and bell crank; *C*, the expansion cylinder; *E*, expansion cylinder injection pump, not shown, drawing brine from the jacket *H* and forcing it in a spray into the expansion cylinder, by which the brine is quickly cooled and discharged with the cold air into the upper section of the brine jacket and tank; *F*, the freezing can or tank, shown in Fig. 530, above the insulated cylinder.

The whole apparatus as completed in 1850 seems to have been the result of several years of study and experiment, and as now viewed was a most complete and advanced conception of the later developments of refrigeration by compressed air as made by Lightfoot, Hall, Bell, and others in England and on the Continent, and by Hunt, Allen, and others in the United States; for, in leaving out some parts of Dr. Gorrie's machine, the principles of all the later machines are covered.

A reference to our illustration will show the details of construction of the compressed-air freezing apparatus of Dr. Gorrie; the power for running the machine not being shown. A charging tank, containing fresh water for supplying the freezing can, is placed overhead. The other lettering indicates details readily understood by inspection.

A reference to our illustration will show the

COMPRESSED-AIR REFRIGERATING MACHINE AS MADE BY J. AND E. HALL, DARTFORD, ENGLAND.

The machine consists of three cylinders, fitted with metallic pistons placed side by side, and connected by a crank shaft, common to all, by means of piston rods, crossheads with slipper

guides, and connecting rods, in the manner common with ordinary horizontal engines. The same crank shaft drives a water-circulating pump, and beneath the frame which carries the whole mechanism is a tubular refrigerator. The lower cylinder in Fig. 532 is of the kind ordinarily made for steam engines, and may be constructed with expansion valves, steam jacket, and all other accessories suitable for a steam engine of the best construction.

The power developed in this cylinder is transmitted through to the crank shaft, by an overhung crank, to a centre crank, which actuates the piston of the middle or air-compressing cylinder, which is water-jacketed, and fitted with double slide valves, through which air is drawn in from the outside atmosphere and delivered, compressed to about 45 pounds per square inch, and at a temperature of about 250° , to the tubular refrigerator. The hot air circulates through a number of metal tubes, round the outsides of which passes a current of water

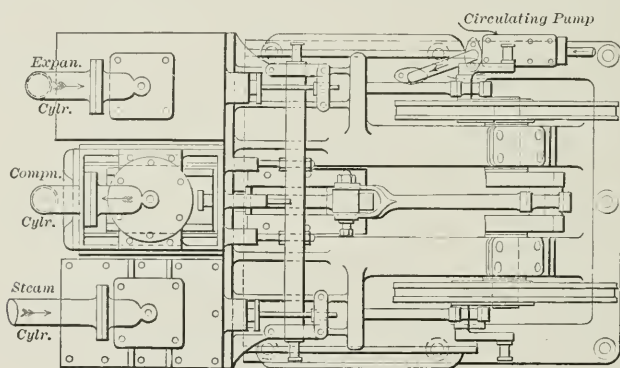


FIG. 532.—PLAN, HALL AIR-REFRIGERATING MACHINE.

supplied by the circulating pump, actuated by the crank shaft. The water rises about 10° in temperature, and carries off, in the form of heat, a portion of the energy of the steam engine. The compressed air, reduced to nearly the normal temperature and at a pressure of 45 pounds per square inch, next enters the upper cylinder on the diagram, through double slide valves, and is made to expand, doing work upon the piston, and there-

fore its temperature falls in proportion to the amount of energy communicated to the crank shaft, which energy is applied to reduce the work to be done by the steam. The temperature of the air is reduced by this means to as much as 130° below the freezing-point. In some cases, instead of drawing air into the compression cylinder from the atmosphere, it is drawn from

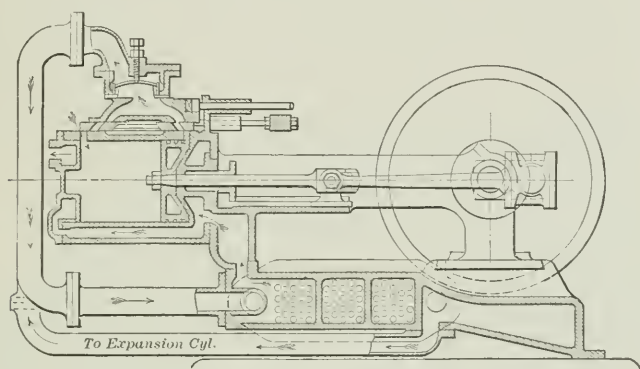


FIG. 533.—SECTION, HALL AIR-REFRIGERATING MACHINE.

the refrigerated chambers, and is made to pass over a number of tubes containing the compressed air, which is thus cooled to a still lower temperature than was effected by the cooling water, the result being that a relatively lower temperature is obtained after expansion. Simple as the process appears to be, yet, to obtain the best results, great nicety is required in the proportions of the cylinders, in the extent to which the air is compressed, the degree to which the air is expanded, and in the practical details of the valve gear, which are especially important with respect to the difficulties attendant upon the formation of snow and ice derived from the freezing of the moisture always contained in the air. It is the successful treatment of these details which makes the difference between an economical and trustworthy machine and a wasteful or uncertain one. When applied to refrigerate the holds of vessels engaged in the dead-meat trade, the money value depending on the efficiency and trustworthiness of a machine is very large.

Setting aside friction, the power necessary to drive the circulating pump, and the heat represented by radiation and conduction, the useful work done by the steam is measured by the quantity of heat carried off by the water circulating round the cooling tubes and the compression cylinder. The theoretical amount of cooling is easily determined.

The air under an absolute pressure of four atmospheres, and at a temperature a little above that of the surrounding atmosphere, say at 60° , is expanded along the adiabatic curve to one atmosphere; the absolute temperature at the end of the operation will therefore be theoretically—

$$\frac{520^{\circ}}{\left(\frac{4}{1}\right)^{0.29}} = 348^{\circ} \text{ absolute.}$$

which is 144° below the freezing-point, instead of the 130° attained in practice. The air in expanding absorbs a certain amount of heat from the cylinder, and hence the slight discrepancy.

In these machines about 50 per cent of the work of the compression piston is returned by the expansion piston as claimed when operated on cold air drawn from the refrigerating room.

THE ALLEN DENSE-AIR ICE MACHINE.

The distinguishing feature of the Allen dense-air ice machine (the invention of Mr. Leicester Allen, of New York) is, that it takes for compression not air of atmospheric pressure from the open atmosphere or from cooled chambers not air tight, but air of considerable pressure which is contained in the machine and in a system of pipes.

This air under pressure (generally 60 or 70 pounds) is taken in by an air compressor and compressed to commonly 210 or 240 pounds. This heats up the air, storing in it such amount of heat as is the equivalent for the work expended upon the compression. It is then passed through a copper-pipe coil im-

mersed in circulating water, which removes the heat to nearly the temperature of the water.

Then the air passes into the valve chest of the expander, which is, in construction, a usual steam engine with a cut-off valve. The valves admit the highly compressed air upon the piston to a certain point of the stroke and then shut it off. The piston continues to travel to the end of the stroke, the air exerting pressure upon it (constantly diminishing). This takes

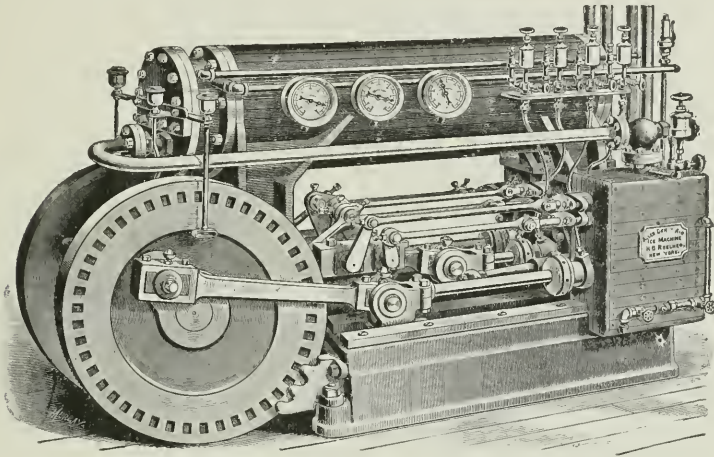


FIG. 534.—AIR COMPRESSOR AND EXPANDER.

Horizontal type of the Allen system. H. B. Roelker, 41 Maiden Lane, N. Y. City.

out of the air such a quantity of heat as the work performed by the air, while expanding, requires for its performance.

The result is a very low temperature of the air at the end of the stroke. The return stroke of the piston pushes it out through thickly insulated pipes to such places as are to be refrigerated, viz., the ice-making box, the meat chamber, and the drinking-water butt. In all these the air is tightly enclosed in pipes or other strong apparatus, being under the original pressure at which it entered the compressor (60 or 70 pounds), when the cold is given out through the metallic surfaces.

The machine usually consists of the following parts, referring to Fig. 536:

A. The steam engine, which is of usual construction, and to its crank shaft the air compressor and the expander are linked. The expander helps the steam cylinder and the air compressor takes the power.

B. The compressing cylinder, which is constructed with

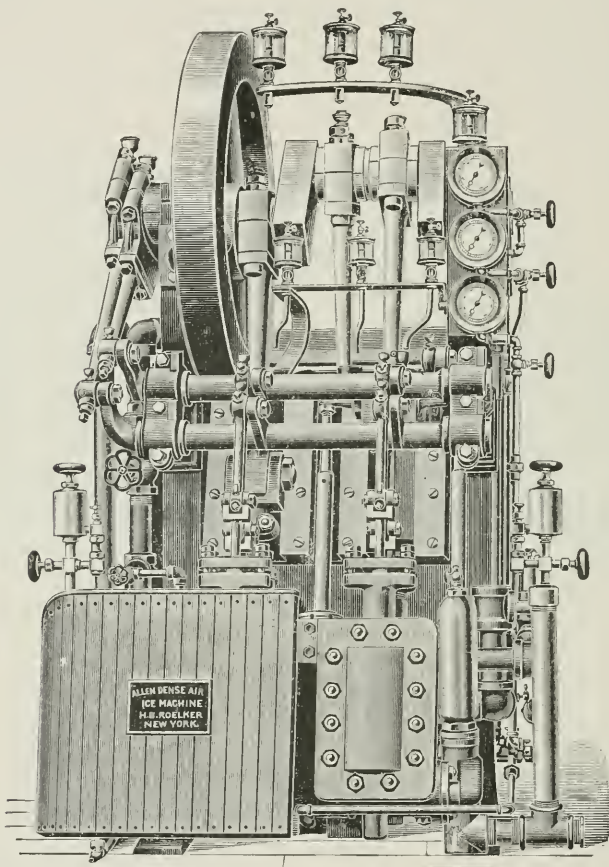


FIG. 535.—AIR COMPRESSOR AND EXPANDER.

Vertical type of the Allen system.

slide valves instead of the usual conical lift valves, in order to move more quickly and noiselessly.

C. The copper coil placed inside of a cylinder containing circulating water. In this the highly compressed air is cooled to nearly the temperature of the water.

D. The expander cylinder, which is constructed like a usual steam-engine cylinder, with slide valve and cut-off valve. It must cut off the pressure at such a point that the expanded air at the end of the stroke of the piston is very nearly of the same pressure as the air contained in the system of pipes. If it were of much higher pressure it would, at exhausting, warm up again, by exerting its remaining power in producing velocities and frictions inside of the apparatus.

E is a trap which gathers out of the cold air the lubricat-

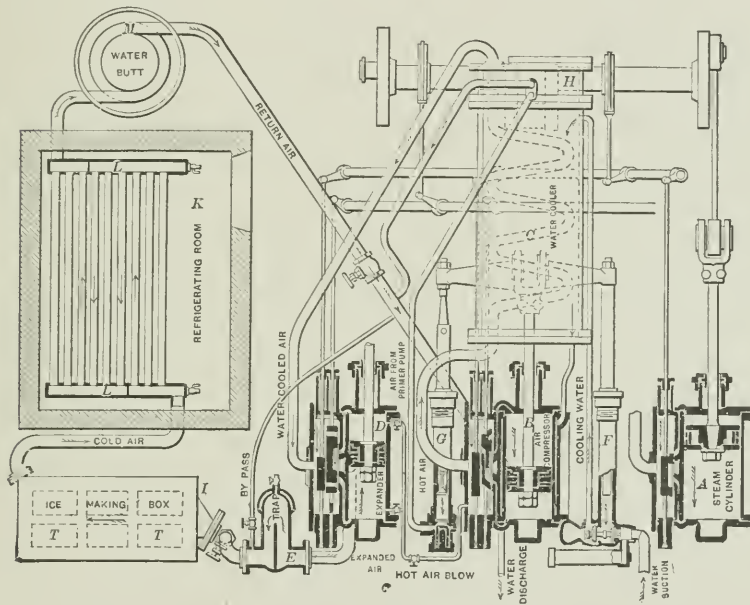


FIG. 536. - CYCLE OF COMPRESSED-AIR REFRIGERATION.

ing oil which is used in the compressor and expander cylinders; also some snow. It contains a jacket connectable to steam, in order to liquefy the frozen contents when they are to be blown out.

F is the water pump which circulates water around the copper coil *C*, and through a water jacket which surrounds the working cylinder of the air compressor *B*, in order to prevent the heat from injuring the packings.

G is a small air-compressing pump which takes air from

the atmosphere and pushes it into the machine and pipe system. This charges the system with the requisite air pressure when the machine starts to work, and maintains the pressure against leakages occurring at the stuffing-boxes and joints. This air contains the usual atmospheric moisture; and to expel this, the outlet pipe from this pump passes the air through the trap *H*, where it is cooled by being forced into very close contact with the cold head of the reservoir for coil *C*. This cooling under pressure and contact with moist surfaces deposits out of the air about 80 or 85 per cent of the contained moisture, which is then drained off by pet-cocks, leaving pure air for the refrigerating work. This is of great importance, as the large amounts of latent heat in the water vapor and of latent cold in frozen water would produce very serious losses in the result of the machine if the air contained water, which would be subject to the heating and freezing processes which occur in the machine. Surplus air is blown off by a small safety valve.

The air pistons are packed with leather soaked in castor oil.

The air stuffing-boxes contain, first, a few rings of Katzenstein soft metal packing rings, then a hollow oiling ring, then outer layers of fibrous packing, usually square Garlock packing. The oiling ring is kept full of oil by a sight-feed pressure lubricator which is connected by a pipe to the stuffing-box.

The air pushed out by the expander is practically of about -35° to -55° F., depending upon the temperature of the cooling water and upon internal leaks and frictions. The pipes lead it first through oil trap *E*, for purification, then to the ice-making box *I*, which consists of a casting, forming pockets *T*, for the reception of sheet-iron ice cans. This casting is set in a strong and tight-jacket casting with internal bulkheads, formed so that the cold air which is led into the space between jacket and ice-can pockets must pass closely along the surfaces of the pockets.

The small space between the sheet-iron ice cans and the inside of the pockets is filled with a solution of about equal

weights of chloride of calcium and water, which withstands the cold without freezing. It provides a good conductor for the cold and keeps the cans from freezing fast in the pockets.

For larger apparatus, a wrought-iron tank, filled with refrigerating pipes, and ice cans, all immersed in the above brine, are used.

From the ice-making box the cold air is led to the meat chamber *K*, where it is passed through a system of refrigerating pipes *L*.

Frozen meat can be kept practically without change for an almost indefinite time. When kept at nearly the freezing-point without change it will remain for a number of weeks in good condition. A good practical rule for the amount of refrigerating pipes required in the meat chamber to keep this at the freezing-point is: One square foot of pipe surface for every $2\frac{1}{4}$ to $2\frac{3}{4}$ square feet of interior surface of well-insulated meat chamber, omitting interior divisions. It is necessary to arrange the pipes so that the air in them is compelled to pass all surfaces with fair velocity.

From the meat chamber the cold air goes to the refrigerating pipes in the drinking-water butt *M*, passing first to the bottom layer and then gradually upward.

After that it returns to the compressor inlet of the machine.

In arrangements where all the cold is not taken out of the air by the refrigerator apparatus, the highly compressed air after cooling in the copper coil is further cooled in a special apparatus, where it is brought into surface contact with the returning and still cold air, before entering the expander.

Temperatures of 70° to 90° below zero are thus practically obtained in these machines.

It is of the greatest importance that all apparatus containing artificially cooled air or brine should be very heavily insulated with air-tight and waterproof material, because the water vapor of the atmosphere is attracted with great force to all cold sur-

faces, destroying fibrous materials as soaking them in water would do, and consuming much cold by its latent heat.

The vertical machines have the same parts as the horizontal machines, only of different dimensions and different detail of position.

COLD STORAGE AND COLD ROOMS FROM THE DIRECT EXPANSION OF COMPRESSED AIR.

In view of the largely increasing demand for the means of preserving food in the warmer sections of the United States, and in tropical climates, where ice cannot be obtained or the cost is so great as to preclude its use, the expansion of compressed air as a constant cooling medium is one of the means at the command and control of every one who is able to place a small outlay for a valuable boon to household comfort; and for the profit that may be realized from the power to preserve fruit, vegetables, and meat for sale, or for the time and opportunity for shipment to a market.

There are large tracts of country in the southern section of the United States in which are situated plantations and farms, the owners and managers of which, having the financial means to supply comforts to life by the use of cold preserved food, yet are entirely beyond the reach of ice, either natural or artificial; with them, such wants may be supplied by means of any small power, such as a windmill, a waterfall, a gasoline or oil engine, operating a pump for the compression of air. In Mexico and the Central American and South American States, the field for useful work by wind and water power alone for contributing to domestic comfort by the preservation of food is immense; where power from nature as through a windmill or water wheel can be utilized. The distance need not be considered beyond the cost of a small pipe for conveying the compressed air, as a considerable length is needed to cool the air to its normal temperature when it has been heated by the operation of compression; when by expansion to atmospheric press-

ure an approximate amount of heat may be eliminated from the expanding air as was accumulated by its compression, and from which a large cooling efficiency may be obtained.

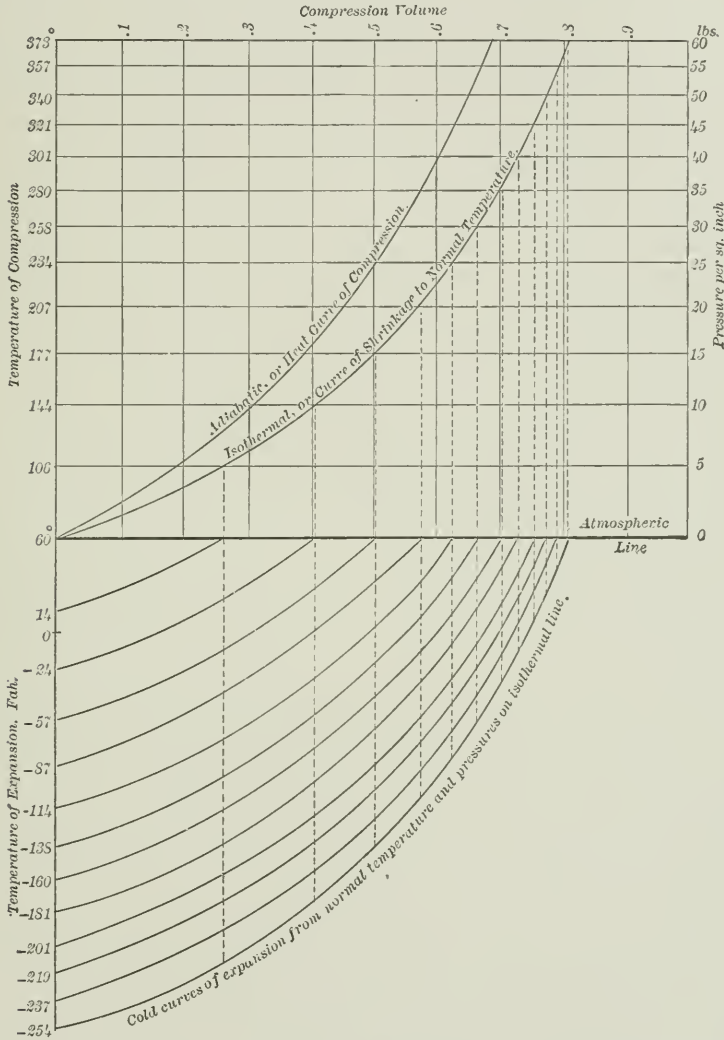


FIG. 537.—THEORETICAL DIAGRAM OF ISOTHERMAL AIR COMPRESSION AND ADIABATIC EXPANSION FROM VARIOUS PRESSURES AND NORMAL TEMPERATURE OF 60° F.

The graphic diagram (Fig. 537) has been made to show at sight the theoretical cooling effect produced by the free expansion of dry air from various pressures and from the normal

temperature of 60° F. The conditions of air expansion for any natural temperature of the stored air may be found by simply subtracting the difference from the expansion column when normally above 60° , or adding when below 60° . Thus, in an atmospheric temperature of 80° , the cold produced by expanding from 20 pounds pressure would be -67° instead of -87° , as shown in the diagram. From 50 pounds pressure and 90° atmospheric temperature, the cold air of expansion would be -108° instead of -138° , as in the diagram; thus for any atmospheric condition of temperature and pressure, the theoretical condition of cold by expansion may be known by simple inspection of their several relations as shown in the diagram.

The diagram shows much that is interesting in regard to the general conditions and effect of air compression and expansion. It will be seen that the column of pressures on the right corresponds with the column of heat developed by compression on the left, while the upper or adiabatic curve shows the condition of temperature, pressure, and volume at the moment of compression. The lower or isothermal line shows the shrinkage of the volume due to the cooling of air to its normal temperature.

The vertical dotted lines from the intersection of the isothermal line with the horizontal lines of pressure, meeting the atmospheric line from the starting-points for the curves of expansion, are extended on the same scale of temperature corresponding with the scale of compression.

The intersections of the dotted lines extended through the curved lines of expansion show also in a graphic way the fractional expansions from one stage of compression to another lower one, as measured by the expansion scale at the left-hand side. Thus when a volume of air at 60 pounds pressure and 60° temperature is expanded to 30 pounds pressure, its temperature will fall to the intersection of the extended dotted line of 30 pounds pressure with the 60-pound curve, which measured on the expansion scale is -57° ; and so on for any other pressures.

In applying the conditions of air expansion to the practical effects of refrigeration or the cooling of rooms for cold storage and preservation of food, a large deduction from the theoretical figures for the degree of cold by air expansion must be made for success.

The absorption of heat from the walls of a cold room, the cooling of a large body of air in the room and of food products stored, and the greater loss from frequent opening of a cold room for the removal and refilling, with the natural leakage of cold air around the doors, make the margin of loss in cold-air production a larger one than at first appears when brought into actual use.

The amount of heat contained in a given volume of air is about $\frac{1}{3444}$ of the amount contained in the same volume of water from any number of degrees change of temperature at ordinary climatic temperatures; so that there is a large margin between the volume of cold air required to cool a room filled with air only and the volume required to cool a room filled with fruit, vegetables, milk, butter, or meat containing from 50 to 90 per cent of water, and of which the solid parts also have a far higher specific heat than air.

This property of water-loaded food accounts for the time required to cool a loaded cold-storage room over the time required for cooling an empty one, as well as the necessity for so packing the material of storage that the cold air can circulate freely and bring every part to the required temperature in the shortest possible time.

As to the work that compressed air will do in cooling rooms, there is a large marginal range in the quantity of free air required for a specific temperature, due to the conditions of temperature of the material to be cooled and the amount of compression in the air to be expanded for this duty, less the work duty of expansion and the losses by radiation and leakage.

Assuming, for example, a cold room for a farm or plantation, of 1,000 cubic feet capacity, or say 12 feet square by 7 feet high,

thoroughly insulated, with a double door at side for storing; a single or trap door with a small ventilator at top, with steps from the trap door for every-day use, and also lighted from the top (by this means a loss of cold air is prevented by its greater specific gravity holding it at the bottom). The room may be kept uniformly at 36° F. in an outside temperature averaging 80° . To cool such a room without storage material, from 80° to 36° requires a loss of 44° in a volume of 1,000 cubic feet of air, say 77 pounds, the specific heat of which is 0.2375 water = 1. Then $77 \times 0.2375 = 18.2$ heat units must be absorbed for every degree of change in temperature. Then $18.2 \times 44^{\circ} = 800$ heat units must be abstracted to bring it to 36° F., leaving out the cooling of the walls, displaced air, and leakage, which will be only a matter of time in the initial operation.

Assuming to use an air pressure of only 30 pounds per square inch, then in the graphic diagram, tracing the dotted line from the isothermal curve junction of 30 pounds and following its curve of expansion, we have $-138 + 60^{\circ}$ to the atmospheric temperature = 198° difference in temperature to be overcome by expansion from 30 pounds pressure, or 198 heat units per pound of air. Then $\frac{800}{198} = \frac{4.04}{.2375}$, or 17 pounds $\times$ 13.1 = 223 cubic feet of free air at 30 pounds pressure will be required to cool the room to 36° .

A compressor of 5 cubic feet per minute capacity, using less than 1 horse power, will furnish enough air to reduce the temperature of the room from 80° to 36° , in which the displacement of air in the room by the addition of 223 cubic feet of cold air should nearly neutralize the loss of effect by resistance and radiation, when the theoretical time $\frac{223}{5} = 45$ minutes may be doubled to about $1\frac{1}{2}$ hours, and should then easily furnish cold air for absorption of heat from the material of storage and to supply the waste made necessary by ventilation and radiation with a constant work of less than a half horse power. This

power comes within the scope of a cheap class of water wheels, water motors, and the smaller sizes of gasoline and oil engines and windmills.

Where intermittent power must be used, as with windmills and power engines, a system of storage of compressed air may be used with perfect satisfaction as affording a constant flow of air into the cold room and also into a small refrigerator, which will be found a most useful adjunct for household use for cooling drinking-water.

The amount of pipe surface required for cooling compressed air to the normal temperature is a matter of much importance, as its delivery at the point of expansion, to be effective, must be at, or very near, the temperature of the outside atmosphere.

The method of keeping the air-cooling pipe at the proper temperature fixes the amount of pipe surface to be provided.

For 30 pounds pressure, 15 square feet of cooling surface per cubic foot of free air used per minute is a fair proportion for an air-cooling coil exposed to a free circulation of the atmosphere and shaded from the sun's heat.

This would indicate a coil of 150 feet of $1\frac{1}{2}$ -inch pipe for the requirement of a cold room as above stated, which may also include the leading pipe from compressor to cold room, if favorably situated for cooling. Where it is convenient to use water for cooling, either by a sprinkler or by submerging the coil in a tank of water fed from a stream or by pumping, the size of the coil may be greatly reduced, according to the temperature of the water.

For an intermittent power as a windmill, or a gasoline engine that would not be convenient to run at night, a storage of air will be necessary by the use of a proportionally increased power during the day for accumulating compressed air in tanks. For night cooling, after the room has once been brought down to the required temperature, the quantity of air per hour will be much lessened, so that the estimated storage of sufficient air for a ten-hours' run of the above plant will require tanks to

hold about 1,200 cubic feet, or say 3 tanks of cylindrical form 5 feet diameter, 21 feet long. As the atmospheric temperature always falls at night in tropical and semi-tropical regions, the conditions of compressed-air supply may be much modified in the storage quantity above outlined by partially closing the air-inlet valve; and where constant power can be obtained, the whole question of cold storage for private use becomes a cheap and simple one.

The arrangement of the nozzle or orifice for delivering the compressed air, and at which point the expansion takes place, is important, and requires its area to be exactly gauged to the proper size for the delivery of the desired volume of air at the assigned pressure. At 30 pounds pressure, air flows through an orifice in a thin plate at the rate of 525 feet per second. Then for the plant as above described, for the issuance of 5 cubic feet of free air per minute under a compression of 3 volumes in 1, is $\frac{5}{3 \times 60} = 0.02777$ cubic feet of compressed air per second, and $\frac{0.02777}{525} = 0.0000529$ of a square-foot area. Then $0.0000529 \times 144 = 0.0076176$ of a square inch. Then enlarging for the coefficient of efflux, the orifice should be $\frac{1}{8}$ -inch diameter, with a needle valve in it to adjust or to shut off the air flow when required. Means should also be provided for blowing off any water that may condense in the air pipes or storage tanks by the cooling of the air after compression.

With proper care and a moderate outlay the system of cold storage by compressed air becomes a simple, efficient, and economical adjunct to the living comforts of every home in a warm climate not blessed with a nearby ice-making plant.

COOL WATER FOR DRINKING IN THE MACHINE SHOP.

Mr. Frank Richards in *The American Machinist* has made the following suggestion for obtaining this desirable comfort, in shops using compressed air:

"A vertical cylindrical reservoir should be provided and connected to the water supply. This reservoir would be constantly full of water, and while contained therein the cooling of the water would take place. The water should enter the reservoir at the top, and be drawn off at the bottom, and the draught pipe after leaving the reservoir should be as short as possible, so that the water after being cooled may not have a chance to warm up again. The cooling of the water would be accomplished by the passage of expanded air through a coil of pipe closely surrounding the reservoir, the air entering at the bottom of the coil, and escaping at the top. The air should be brought to the cock which controls the admission to the coil at full pressure, say, 70 to 80 pounds gauge, and at the temperature of the surrounding air. The compressed air, while under full pressure and before reaching this point, should have been allowed to deposit all the moisture it could get rid of by passing through a suitable chamber or air receiver *after* being thoroughly cooled. A receiver near the compressor, and through which the air passes before it is entirely cooled, serves to equalize the pressure against sudden fluctuations, but it does not get rid of the moisture. A chamber through which the air may pass after it is thoroughly cooled will do so. As the air comes to the coil under pressure, and at normal temperature, upon being released from pressure, and flowing into the coil at atmospheric pressure, and expanded to four or five times its previous volume, it is much lowered in temperature, and immediately begins to draw heat from the walls of the water reservoir which it encircles, thereby cooling the water contained in the reservoir. The air coil instead of surrounding the water reservoir may be entirely within it, and directly in contact with the water. The latter is the better arrangement, but in either case the entire air coil and water reservoir must be enclosed in a thoroughly effective non-conducting jacket or covering.

"Now, the getting of this coil and reservoir and all that, and rigging it up properly, is too great an undertaking, and

one that few will be likely to undertake at first, so we have to suggest a way of doing it all with such material as is generally available, and which, because we have it handy, we generally assume to cost nothing. Take a $1\frac{1}{4}$ -inch pipe 100 feet long—50 feet might be long enough—place it horizontally, and connect one end of it to the compressed-air supply with a suitable cock to control the escape of the air. Leave the other end of the pipe open and enclose the whole of the pipe, after passing the air-admission cock, in a thick non-conducting covering. If you have nothing better at hand take plenty of paper, winding it on layer after layer and covering the whole pipe. Then lead a $\frac{3}{8}$ -inch water pipe into the open end of the air pipe, and let it come out by a tee or otherwise at the other end of the air pipe, and you have the whole apparatus. The air in this case, as before, should be brought to where it is to be used thoroughly cooled and with all its water discharged."

Chapter XXXIV.

THE HYGIENE OF
COMPRESSED AIR

THE HYGIENE OF COMPRESSED AIR.

It is more than half a century since the properties of compressed air as a remedial agent were put forward as a theory and in practice in "compressed-air baths," and claimed to be especially useful in the treatment of pulmonary diseases and of dyspepsia. As the pressure employed in the air baths was comparatively slight, usually from 8 to 10 pounds per square inch, the effects observed differed widely from those produced by the high pressure employed in engineering and submarine work. This difference is not only in degree but also in kind, and therefore the literature relating to compressed air as a remedy, although extensive and interesting, throws no light upon the effect of high pressure upon the human system.

It is only in the actual work of caisson sinking and diving in submarine work that reliable conditions as to the influence of compressed air on our vital condition have been observed. It is noted that at three atmospheres absolute, 30 pounds gauge pressure, it is impossible to whistle; that in compressed air at considerable tension, every one speaks through his nose; that men under air pressures in ascending caisson ladders were much less out of breath than with the same work in the open air.

In speaking, the tongue moves stiffly and with difficulty. Sounds are not heard with their usual intensity. The secretion of urine is decidedly increased.

The most usual affection is muscular pains, occurring either alone or ushering in other symptoms. When, through lack of proper ventilation, the caisson air becomes impregnated with the smoke of lamps and carbonic-acid gas from respiration, all pathogenic conditions become intensified.

Experience has taught that the ill effects are in proportion to the rapidity with which the transition is made from the compressed air to the normal atmosphere.

Under pressures of 40 to 50 pounds per square inch, taste, smell, and the sense of touch lose their acuteness.

During the time pressure is increasing the hearing is affected, with a feeling of increasing warmth in the skin, as if going into a warm room. The pulse becomes small and thready, sometimes imperceptible. Venous blood becomes of a bright red hue. The lungs seem to increase in development, while the motion of the ribs is reduced. Shortness of breath is occasionally produced; increase of appetite is experienced, seldom thirst.

While the pressure remains stationary, all subjective phenomena disappear, to return again during locking out from a caisson, when ringing of the ears and bulging of the ear-drums are observed; taste and smell return; a prickling sense of warmth is felt in the nostrils, which is sometimes followed by bleeding at the nose. At the same time the rapid decline of the temperature from the expansion of the air causes extreme chilliness.

On going out from a caisson, intense pains in the ears and muscles sometimes occur, which are much modified or avoided by a slow change of air pressure.

A good rule has been established to allow of five minutes for locking out from 7 pounds pressure; seven minutes from 15 pounds; ten minutes from 20 pounds; twelve minutes from 30 pounds, and so on, with proper increase of clothing to counteract the chill from the decreasing pressure in the air lock.

A serious inconvenience is experienced by workers in caissons, where gas or lamps are used, from the unconsumed carbon or smoke floating in the dense air. Its inhalation produces more or less irritation of the air passages and gives rise to a very characteristic black expectoration, which often continues for a long time after the caisson work is finished.

Comparative immobility of compressed air from its density, which retards the velocity of the air currents necessary to perfect combustion, has been assigned as the cause of smoky lamps and gas-jets in caisson work. A watch beats slower in compressed air.

The following abstract from the prize essay of Andrew H. Smith, M.D., on the effects of high atmospheric pressure in caissons, is of great value to workers in compressed air:

EFFECTS OF COMPRESSED AIR.

The effects of a highly condensed atmosphere upon the system may be divided into those which are physiological or consistent with health, and those which are pathological and constitute or induce disease.

The physiological effects will be considered according to the organs or functions in which they are exhibited.

Effect on the Hearing: It is a law of acoustics that within the limit of mobility the denser the medium through which the sound waves are communicated, the larger the wave, and therefore the louder the sound. This supposes, of course, that the ear itself remains under normal conditions. Such, however, is not the case when the observer is in a highly condensed atmosphere. The unusual pressure upon all parts of the auditory apparatus opposes a mechanical obstacle to the freedom of vibration, which is essential to perfect hearing. Hence, although larger sound waves may strike upon the ear-drum, feebler impressions are communicated to the auditory nerve, and the sound appears to be fainter than in the open air. Thus by repeated experiments, I found that a watch that could be heard distinctly at a distance of eighteen inches in a very noisy place in the open air, could not be heard at a greater distance than two inches in the comparative silence of the caisson.

At the same time the *velocity* of the waves of sound is greater, and hence the *pitch* is higher. A deep bass voice is

changed to a shrill treble, and the prolonged, heavy sound of a blast is so modified as to resemble the sharp report of a pistol.

This modification of sound is very striking, and is almost the only thing to remind the casual observer that he is moving about in an atmosphere three or four times as dense as that to which he is accustomed.

A curious fact, noticeable under these circumstances, and one which was long ago observed in diving-bells, is that it is impossible to whistle. The utmost efforts of the expiratory muscles is not sufficient to increase materially the density of the air in the cavity of the mouth, and hence on its escape there is not sufficient expansion to produce a musical note. A similar difficulty, though in a less degree, is experienced in speaking, and for this reason protracted conversation is very fatiguing.

Effect upon Respiration: In a highly compressed air, the frequency of the respiration is increased. Dr. Jaminet gives the rate as 21 per minute, with a pressure of 33 pounds, which accords with my own observations. He ascribes this increase of three or four per minute to an increased absorption of oxygen. Experiments show, however, that simply increasing the supply of oxygen *diminishes* the frequency of respiration instead of increasing it. The true explanation, I think, is to be found in the fact that the quantity of carbonic acid held in solution by blood, as by water, is in proportion to the pressure to which the gas is subjected; and hence with the pressure existing in the caisson, the elimination of carbonic acid from the blood would not be as perfect as under normal circumstances, unless the air in the lungs were more frequently changed. As observed by François and Dr. Jaminet, the depth of the inspirations is also increased.

Effect upon the Circulation: It has been shown by numerous observers that under a slightly increased pressure, such as is employed in compressed-air baths, the pulse loses in frequency from the first. This is doubtless due to an increased absorption of oxygen by the blood, which thus affords a suffi-

cient supply to the tissues without the necessity of keeping up the usual activity of the circulation. In the course of some experiments undertaken nearly four years ago, I demonstrated that the same effect results under a normal pressure from adding oxygen to the air inhaled. But as the pressure increases the question is transferred from the domain of chemistry to that of mechanics. The condensation of the tissues from the pressure to which they are subjected, and the consequent narrowing of the vessels, oppose a physical obstacle to the circulation, which is felt before the blood has time to become surcharged with oxygen, and while there is still a necessity for an active circulation. The labor of the heart is thus increased, and its action, in consequence, excited. I have frequently seen the pulse rise to 120 immediately upon entering the caisson, where the pressure was from 30 to 35 pounds to the inch. But after the lapse of a period varying in different cases from half an hour to two hours, the pulse falls back to its normal standard, or even, it may be, below it. The blood has now become saturated with oxygen, and consequently a less active circulation is demanded.

Doubtless, if the pressure were very gradually admitted, the preliminary rise in the pulse would not take place, the favorable chemical action keeping in advance of and counteracting the unfavorable mechanical conditions.

The effect of high atmospheric pressure upon the *volume* of the pulse is always, according to my observation, to diminish it. This is easily accounted for by the pressure exerted upon the artery, which prevents its yielding readily to the expanding force of each successive wave of blood. Hence, the pulse is small, hard, and wiry. These characteristics are independent, in a great degree, of the *frequency* of the beat, although as the heart recovers from the irritable condition into which it is thrown by the sudden increase of the pressure, and settles down, so to speak, more calmly to its work, it contracts with more force, and the pulse gains somewhat in volume.

It is remarkable that the wide variations in the pulse-rate observed were not accompanied by any symptoms appreciable to the individual. A man with a pulse of fifty-two, and another with one of one hundred and sixteen, felt equally well, and each was entirely unconscious of anything unusual in the heart's action.

The effect of the pressure upon the cutaneous vessels is shown by the pallor of the face, which is very marked, and continues for fifteen or twenty minutes after leaving the caisson. The hands, too, feel shrunken, and the palmar surface of the fingers is often shrivelled, as if soaked in water. The pressure acting upon all sides of the fingers empties them to a considerable extent of blood, rendering the skin apparently too large for them. The veins, too, on the back of the hand seem to be effaced.

Effect upon Temperature: In none of the reports upon the effects of high pressure as employed for engineering purposes, have I been able to find any records of temperature. J. Lange, however, found that under the comparatively slight pressure which is used as a remedy, the temperature of the body suffered a slight decrease. This is, no doubt, due to an increased absorption of oxygen, which has been shown by Mr. Savory and also by experiments of my own to produce this effect.

The temperature of the body in health is kept at about 98.6° F., by the constant evaporation from the surface. But in the caisson, as already mentioned, the air was always nearly or quite saturated with moisture, so that evaporation from the surface must have been practically suspended. With the temperature of the air at 76° , as it was at the time of the observations, and the men engaged in severe labor, it is easy to see how the absence of the cooling process of evaporation from the surface would lead to a rise of one degree of the thermometer. This view is strengthened by the result of three observations on a subsequent occasion, when the temperature in the caisson stood at 81° instead of 76° . The average in this instance was

101°. A rise of five degrees in the temperature of the air could not sensibly affect the rapidity of tissue-change, but, if not counteracted by evaporation from the skin, it would soon tell upon the temperature of the body.

The influence of the hygrometric condition of the atmosphere upon the temperature of the body is a matter of daily observation. On a clear, dry day, with a high barometer, we are surprised to find the thermometer indicating a temperature much higher than our sensations would lead us to expect, while on the contrary, on a cloudy day, with a low barometer, we can scarcely persuade ourselves that the temperature is not many degrees higher than the thermometer indicates. In the dry, clear air of New Mexico I have supported a temperature of 110°, without inconvenience, while in the humid atmosphere of the Florida Keys I have found it almost unbearable at 86°.

Effect upon the Perspiratory Function: Several writers have observed that it is immediately remarked by every one entering a caisson that the secretion from the skin is apparently immensely increased. It is noticeable even when the temperature of the air is moderate, but as this increases it becomes a very serious annoyance. The clothing quickly becomes saturated, which, besides the discomfort it occasions, exposes to great danger of taking cold on going out into the open air.

But a little examination served to show that in the New York caisson, at least, there was really no increase of the secretion from the skin, but that, instead of evaporating, the moisture accumulated upon the surface, and thus stimulated excessive sweating. This was owing to the moist condition of the atmosphere already mentioned, which rendered the drying of the surface by evaporation impossible. The atmosphere possessed to an extreme degree the quality of "mugginess," and the apparently profuse perspiration was merely an exaggeration of what we suffer from in very damp weather, even though the temperature be not extreme.

So far from the perspiratory glands being stimulated by

the density of the atmosphere, it is probable that the anæmia of the skin already described, as resulting from the pressure upon the surface, would tend to lessen the secretion by diminishing the supply of blood to the glands.

That there is not an undue amount of fluid carried off through the skin, is shown by the absence of thirst so generally remarked.

The foregoing explanation of the apparent increase of perspiration is important, as it bears upon the theory of excessive waste of tissue, in which the perspiration is supposed to aid.

Effect upon Digestion: Nearly all authors who have written upon the effects of compressed air agree in stating that for a time, at least, it increases the appetite to a remarkable extent. Indeed this is one of the first and most favorable results observed where compressed air is applied remedially. With this experience my own observations in the main agree. It was frequently remarked by the men working in the New York caisson that their work made them unusually hungry, that they "could not get enough to eat," etc. Of course, it was not possible to obtain any exact data as to the relative amount of food consumed, but from careful inquiries I arrived at the conclusion that it was considerably in excess of what is usual in the case of men engaged in similar labor in the open air. Still, there were many exceptions to the general rule, especially among those who had been long engaged upon the work, and whose general tone was beginning to deteriorate. Among these, loss of appetite was often complained of.

The fact of this generally increased appetite seems to point to an increased waste of tissue, to be supplied by a greater consumption of food. An increased absorption of oxygen, such as we assume to take place, seems from the observations of several authorities to imply greater activity of tissue change as the *ultimate* result. But in this case I think it is scarcely safe to accept this explanation at once as conclusive and sufficient. It may well be questioned whether during the actual sojourn in the

caisson the functions of digestion, absorption, and assimilation proceed normally under the wide departure of the system from its natural conditions. If it could be shown that a considerable portion of the food taken before entering the caisson is but imperfectly digested or assimilated, the subsequent hunger would be readily accounted for. I am not aware that this point has ever been investigated, but I can scarcely believe that such an increase of appetite as is described could depend wholly upon increased interstitial change without giving rise to marked elevation of temperature and other symptoms denoting unusual chemical activity.

Effect upon the Urinary Secretion: Dr. Jaminet, in his observations at St. Louis, found that the amount of fluid secreted by the kidneys was very much increased, in some instances nearly doubled, while the specific gravity was but little, if at all, below the usual average. This shows that the solid matter excreted was also in much greater quantity than usual. But I cannot agree with him in attributing this exclusively to the excessive waste of tissue from over-oxidation of the blood. The explanation is to be found, I think, chiefly in the fact that the skin, as already stated, performs its function very imperfectly, owing to the impossibility of evaporation from the surface when the air is already loaded with moisture, and hence a portion of its duty is forced upon the kidneys, organs always ready to act vicariously for the skin or the mucous surfaces.

Furthermore, the excretion of a large amount of urea indicates a relatively *deficient* oxidation of tissue, and is one of the characteristics of those diseases in which respiration is suddenly embarrassed, as, for instance, pneumonia.

Another circumstance not to be lost sight of is, that the pressure upon the surface acts mechanically to congest all the abdominal viscera, and that congestion of the kidneys, within physiological limits, produces increased secretion of urine.

Chapter XXXV.

LIQUID AIR,
ITS PROPERTIES AND USES

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AIR is the vapor of a liquid, and acts in its properties like the vapor of other liquids. Each of its constituents, nitrogen, oxygen, carbon dioxide, argon, and helium, is also the vapor of a liquid.

In their combination, forming elementary portions of our atmosphere, apart from the vapor of water, their physical properties probably combine or mix in proportion to their parts to produce an average property as found in physical experiments with air. It liquefies at a pressure of 573 pounds per square inch at the reduced temperature of -220° F., and upon a gradual release of pressure commences to boil with a falling temperature. Under a pressure of 294 pounds it boils at -240° F., and at atmospheric pressure boils at -312° F., at which temperature it can be handled like water and used for the exhibition of the effects of extreme cold, and under special conditions has been used as an element of power.

When confined and its temperature rises, the pressure rises with the temperature until at ordinary atmospheric mean temperature it generates a pressure of 12,000 pounds per square inch. The specific gravity of liquid air at its boiling temperature is .94 (water 1.00), its latent heat about 144 heat units per pound—by Dickerson's experiments, 123 heat units per pound. The critical point for air, or the temperature above which it will not liquefy by increased pressure, is -220° F. The phenomena of the critical temperature have been stated as that "there are for every vaporizable liquid a certain temperature and pressure at which it may be converted into the aeriform state in the same space occupied by the liquid; indicating that, above a certain temperature (its critical), a gas or air can

be squeezed down to the volume of its mass as a liquid without liquefying." The relative volume of free air at mean atmospheric temperature is about 800 times its liquid volume. Air has been compressed to 14,000 pounds per square inch, without signs of liquefying at ordinary temperatures, and has been used at 9,000 pounds pressure for blasting rock and coal.

It has been claimed that Johann Naterer of Vienna, Austria, produced air pressures of nearly 60,000 pounds per square inch—which is about the tensile strength of open-hearth steel and twice the initial pressure of exploded powder in a gun—without signs of liquefying. Its density at this pressure is stated by Dewar to be 1.25 (water 1.00). Almagat also carried air pressures up to 45,000 pounds per square inch; and as nothing is stated in regard to temperature, it is assumed in both cases that the critical temperature prevented liquefaction.

When air is liquefied and allowed to boil off at atmospheric pressure, the nitrogen boils off faster than the oxygen, and the resulting free air becomes richer in oxygen.

Pure metals, as stated by Dewar, seem to have no electrical resistance at temperatures near absolute zero. The electric conductivity of carbon decreases with low temperatures and increases with high ones; at the temperature of the electric arc it appears to have no resistance.

The color of liquid air is light blue.

Its use in physical experiments has been a most important one in developing the action of intense cold on the tenacity of metals, in chemical reaction and magnetic effect under temperatures approaching that of interplanetary space.

The lowest temperature as yet artificially produced was obtained in the experiments of Professors Dewar and Wroblewski by the evaporation of liquid air by which a temperature of -346° F. was reached, or within 115° of the reputed absolute zero; beyond which, it is claimed, molecular vibration ceases and the chemical action between all substances is in abeyance.

In physical investigation the convenience for obtaining and

maintaining intensely low temperatures for a considerable time, or sufficient for the manipulation of experiments in physical phenomena, is only of recent date, and this has opened the way for the most noted expansion in the paths of physical research.

The action of extreme cold on the tenacity of metals has become a most interesting inquiry, with results greatly contrasting with former theories, and tending to show a critical temperature in the tenacity of metals not uniform, but widely varying with their crystalline structure.

Thus with steel, iron, copper, brass, German silver, gold, silver, tin, and lead, the tenacity has been found to be largely increased from 60° F. to -295° F., mostly equal to 50 per cent, and in the case of iron to more than 100 per cent; while the highly crystalline metals, zinc, bismuth, and antimony, lose half their strength at the lowest temperature.

A singular incident is the increase in the tensile strength of the fusible alloy of tin, lead, and bismuth of 300 per cent at this low temperature.

The behavior of a magnet at the temperature of boiling liquid air has been found to be somewhat erratic, owing probably to the difficulties attending such experiments; but with final results of an increase of from 30 to 50 per cent of its magnetic strength by the extreme cooling process.

In chemical research the field of operation at extreme low temperatures is so new that but few results of a positive character have been reached, owing to the chemical inertness of all the active elements, as with acids and alkalies.

At the lowest temperature yet reached, nitric acid has no action upon metals, and acids and alkalies may be mixed without evolution.

A most curious physical phenomenon is shown in the condition of meats at the extremely low temperature derived from the evaporation of liquid air; mutton becomes so exceedingly hard that it rings like porcelain when struck with an iron rod, and may be crushed into a fine, dry powder with a hammer, in

which muscle, fat, and bone are undistinguishable, but mingled as dry sand.

Professor McKendrick, in England, has found that microbic life in flesh is so tenacious that it cannot be frozen out, even after exposure to -133° F. for four days; that on thawing and raising to normal temperature, and moisture, activity of life is at once manifested.

A tablespoonful of liquid air poured on about a fluid ounce of whiskey will freeze it at once into flat scales, giving the whole the appearance and color of cyanide of potassium. This may be emptied out on a table, and will remain frozen in that condition for fully five minutes.

One thing that impresses one is that while all molecular motion is practically arrested at this temperature, the odor is perfectly distinct, showing that these particles which stimulate the sense of smell are active and independent of the temperature.

A teacupful of liquid air poured on top of a tank of cold water goes into its spheroidal state instantly, in globules of about half the size of an ordinary marble, which fly around on the surface, leaving a trail of white vapor behind them.

A handkerchief of either silk, linen, or cotton, saturated with the liquid, will be charred and destroyed just the same as if it were put in an oven and browned, though no change of color is apparent. Its evaporation is quite slow, and it may be carried about for a number of hours in an open vessel without entirely disappearing. Absolute alcohol solidifies at -203° F. becoming viscous before solidification like a heavy oil in appearance.

Professor Dewar has found that liquid air, when reduced to its lowest attainable temperature by boiling under a vacuum, becomes apparently solid or frozen; and that when the solid mass is placed in a strong magnetic field, oxygen is drawn out toward the poles of the magnet in a liquid form, showing that nitrogen may be frozen at about -346° F. The temperature for freezing liquid oxygen has not yet been reached. The

evaporation of liquid air greatly increases its proportion of oxygen, and the liquid becomes a vigorous element in combustion even to explosive violence. Any fibrous combustible material, saturated with it, burns with explosive violence. When cotton fibre is wet with oil and with concentrated liquid air, and confined in an iron tube or blasting-hole, it explodes on firing with all the force of dynamite.

The experiments on the properties of liquid air and its bearings upon the properties of all the elements of nature are in progress and promise wonderful development in the knowledge of their chemistry and physical relations.

There are many beautiful experiments that illustrate the properties of liquid air that we do not feel justified in giving in this work. One illustrates the phenomenon of boiling liquid air under a vacuum in a test tube, which produces so low a temperature that air in contact with its surface liquefies and drops from its bottom like rain, while the moisture in the air is deposited on the surface of the tube like snow.

The commercial production of liquid air is a very important discovery, and the future question of economy in motive power may be intimately associated with this liquid. Compressed air, at pressures ranging from 1,000 pounds upward, is conducted from an air receiver through a small pipe, is refrigerated to expel its moisture, and is then conducted into the apparatus which liquefies it completely, without the use of chemicals of any kind,

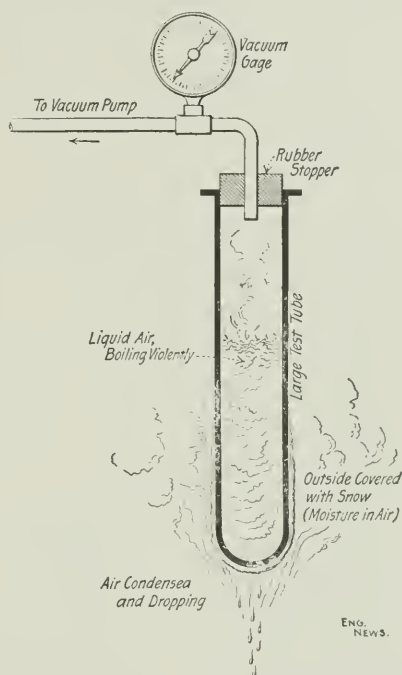


FIG. 538.—LIQUID AIR DROPPING FROM THE OUTSIDE OF A TEST TUBE.

and it flows from this apparatus in a stream about the size of a lead pencil (in the apparatus of Linde) into a glass insulated receptacle, containing about two gallons. This receptacle was filled in a very short time. Of course, being in an open vessel, liquid air has no pressure, but its temperature is approximately -315° F., or 375° below the atmosphere at 60° F. Inasmuch as it boils rapidly on the surface, owing to its absorption of heat from the atmosphere, it looks like milk on the surface, but upon dipping some of it out in a glass and observing its color through the glass, it has very much the appearance of ordinary water. Its temperature is very deceptive, for as it runs from the condenser one may allow it to trickle over the fingers for a short space of time, and it appears to have the atmospheric temperature. The truth, however, of the matter is that it does not come in contact with the fingers at all; the hand being something like 480° warmer than the liquid, it throws the liquid into a spheroidal state and interposes between it and the fingers a film of atmospheric air. The sensation is very much like pushing one's hand into a bag of feathers or into a mercury bath, allowing, of course, for the difference in weight between the mercury and the liquid air. If, however, you immerse your hand in the liquid a sufficient time to establish a contact, the flesh would be burned, the same as if it were exposed to 440° of heat, measured above the atmospheric temperature. If a test tube of $1\frac{1}{2}$ inches diameter, having a couple of pounds of mercury in the bottom, is immersed in liquid air, the mercury will be frozen solid in a few seconds, and may be hammered out and otherwise manipulated the same as lead. An alcohol thermometer of large size will be frozen instantly upon being immersed in the liquid.

An idea of the tremendously low range of temperature may be gathered from the fact that it will take several minutes to thaw out the small bulb of this thermometer by covering it with the palm of the hand.

In Fig. 539 is shown an ideal view of the "Linde" liquid-

air apparatus in its earlier form, in which the air at atmospheric pressure and temperature was taken into the compressor *A* and delivered to the cooler *B*, at from 250 to 500 pounds, where it was cooled to as low temperature as the means would allow; then entering the inner of the double concentric coil *C*, it was delivered at the needle valve *D*, where its expansion into the receiver *E* was regulated. Its expansion to nearly atmospheric pressure produced a very low temperature, but not low enough for liquefaction; but as the cold air was exhausted from the receiver through the annular space between the coils, it cooled the incoming air to such a degree that its own expansion carried the temperature to the required point for liquefaction, in which state it was deposited in the receiver to be drawn off at the faucet. This was a negative or cold refrigerative process, but the final cold exhaust was wasted at *F*.

In Fig. 540 is shown a further improvement of Dr. Linde's liquid-air apparatus, by turning the cold air exhaust into the compressor,

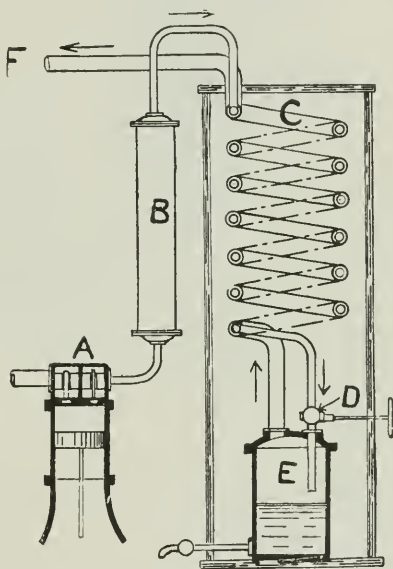


FIG. 539 —LINDE LIQUID-AIR APPARATUS.

thus enabling a colder delivery from the compressor and a colder delivery of the air stream from the cooler by adding ice to its cooling water. This was called the continuous process, by which all the exhaust was used, and as much fresh compressed air drawn in at *A* in the illustration as would supply the loss by liquefaction.

In the Linde apparatus, as shown in our illustration, cold compressed air at 324 pounds per square inch is furnished to the apparatus at *A*, which establishes through the suction

flask being enclosed in a thoroughly insulated chamber, the operation may be as follows:

Taking the air from the primary compressor at 324 pounds pressure and at normal temperature or less by artificial cooling, say to 30° F., the high-pressure compressor carries the pressure with a third of its previous volume to, say, 972 pounds, which will raise the theoretical temperature to, say, 520° F.

This temperature should be so much absorbed by the refrigerator *J* as to allow, at the start of the machine, of a temperature below the normal at the expansion nozzle in the flask. The expansion of the air from 972 pounds to 324 pounds, say 3 volumes, or 43 atmospheres, reduces the temperature by expansion, theoretically, to about 400° below zero F.; but in consideration that the material of the apparatus is at normal temperature and the specific heat of air being of low degree, a large part of this excessive cold* must be absorbed in the material of the apparatus and its insulation, in order to bring the whole apparatus down to a productive temperature. This can be done only by operating the air in a cycle, by which the cold produced by expansion in the flask is utilized in the outer coil for reducing the temperature of the air in the inner coil. The time required for cooling the insulated apparatus to the temperature for producing liquid air in the flask was found to be five hours; when the machine became a constant producer of liquid air at the rate of six pounds per hour.

According to Linde—perhaps its most successful, experienced, and reliable producer—it requires 100 horse-power at the compressor to produce as many pounds of liquid air per hour, and it can develop but a fraction, probably a small fraction, of that amount of power in regasifying. It loses by simple vaporization, even in large vessels, 10 gallons and upward, about 4 per cent, under the most favorable conditions for its preservation, each hour. Its efficiency in the motor is found to be about 4 per cent; that of the steam engine is from 7 to 20 and more, and that of the gas engine ranges to still higher figures.

In the Dewar liquid-air apparatus illustrated in Fig. 542, carbonic acid is used in its liquid state for producing the primary cold by its evaporation and expansion in a helical coil interlocked with the inlet air coil in an insulated cylinder.

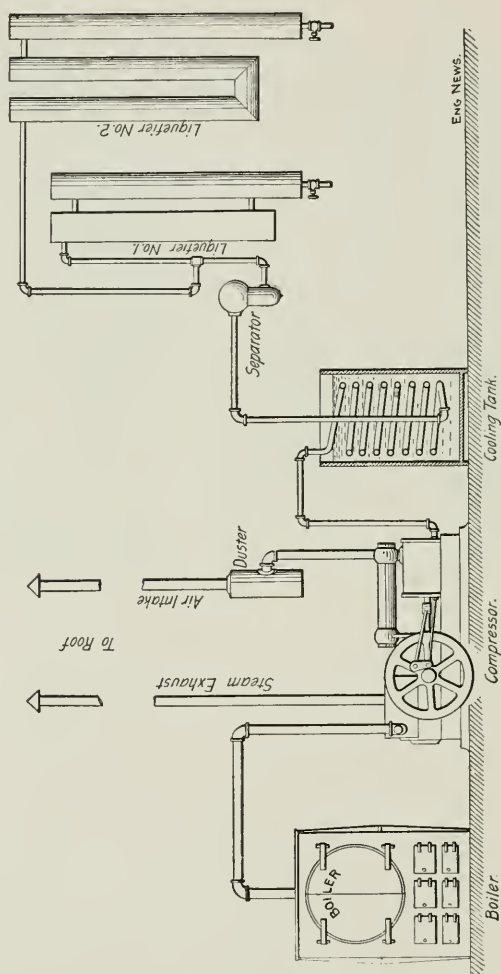


FIG. 544.—THE TRIPLER LIQUID-AIR APPARATUS.

Showing the course of the air from the intake through the dust-washer, the compound compressor, and its intercoolers; through a cooling tank and separator, in which the moisture condensed in the cooling process is trapped and discharged. The air then enters the liquefiers, which are composed of a regenerative system of copper coils, in which the cooling effect of expanding air intensifies the cooling process.

The liquid carbonic acid enters the apparatus at *B*, passes through the helical coil indicated by the black dots, and expands from the needle valve in the centre chamber, which is regulated by the stem and wheel at *C*.

The expanded gas at a very low temperature permeates the whole interior system of air coils and exhausts around the primary inlet coils at *H*. The air, compressed to 1,500 pounds per square inch, enters at *A*, and is cooled by the exhaust of the carbonic-gas exhaust in the outer section, and further cooled by the cold gas surrounding the air coil in the inner section, and is finally expanded at a very low temperature from the needle valve, liquefying a portion, while the excess of cold air at the liquefying temperature is exhausted from the receiver *G* through the annular space containing the last section of the air coil.

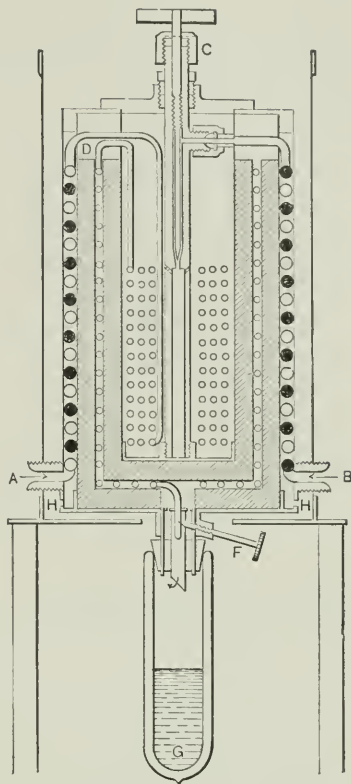


FIG. 542.—THE DEWAR AIR-LIQUEFYING APPARATUS.

In this process advantage is taken of the extreme cold-producing power of expanding carbonic acid, and also of the regenerative power of the final expansion of cold compressed air.

THE LIQUID-AIR PLANT OF THE GENERAL LIQUID AIR AND REFRIGERATING COMPANY OF NEW YORK, OPERATING UNDER THE PATENTS OF O. P. OSTERGREN AND MORIZ BURGER.

The plan (Fig. 543) shows the passage of the air from the outside through a four-stage compression with intercoolers, cleaner, and separator, at which point the air pressure is 1,200 pounds per square inch. So far the operation is identical with any four-stage air-compressing plant.

Continuing the circuit from the after-cooler, the air enters a

separator for the purpose of removing all moisture, oil, dust, or other impurities. Passing on, the air enters the compressed-air coils in the brine or cooling tank, a section of which is shown

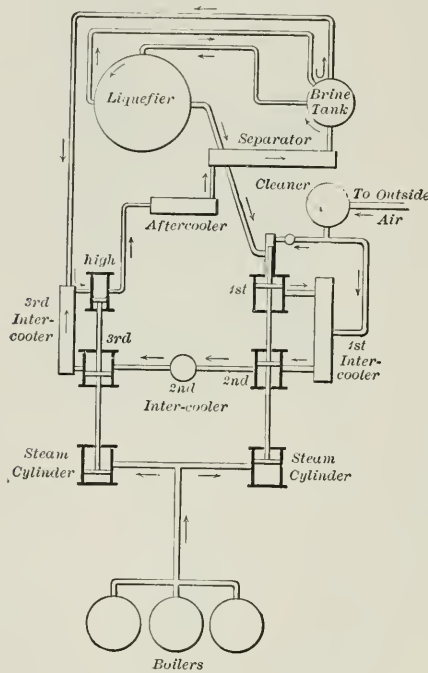


FIG. 543.—LIQUID-AIR PLANT.

drop in pressure and consequent expansion cool the air to a certain extent.

The cooled air passes upward in the exhaust passage of the central header at *E*, and through and around the expanding spiral coils to the outlet to the brine-tank coil. Thus the incoming compressed air is cooled by the brine contact, which in turn is cooled by the expanding air in the interlocked exhaust coils.

This accumulative cooling continues until eventually the critical temperature of air is reached. Then, and then only, a portion of the air passing through the expansion valve liquefies and collects in the small chamber over the second or after-cooler, or reservoir valve, shown in section, lower part of Fig. 545.

in Fig. 544, which is a plan of the interlocking coils of compression and expansion. The compressed cold air entering the coil at *E* and through the coil to the central header at *X*, is expanded through a needle valve into the liquefier, and the remaining exhaust returned to the second central header *E*, and through the spiral interlocking coil to the outer header *X*. The expansion valve is so adjusted as to throttle the air flow and keep the difference of pressure on its two sides at about 900 pounds. This

That portion which does not liquefy, which is, however, intensely cold, of course passes into the cooling tubes as before.

From what has been said it will be seen that the system is a regenerative one and that the air once taken into the system is used over and over. There is, of course, need for new air to take the place of that liquefied, and this is drawn in from outside through the cleanser, shown in Fig. 543, by the by-pass from the cleanser to the low-pressure cylinder of the compressor with a suitable automatic valve. This cleanser consists of an inlet tube coming from the roof of the building, and extending down to the bottom of the containing tank. From the bottom of the four arms, the air bubbles out and up through water to a coke filter, where it is thoroughly scrubbed. It is also subjected to a water spray, after which it remains in the upper portion of the tank until needed by the system, when it is drawn into the low-pressure cylinder.

Returning to the liquefier again, it will be seen that opening the after-cooler valve allows the liquefied air to pass into the reservoir below, where at first it will immediately volatilize, owing to this portion of the apparatus being warm. This will produce in the reservoir sufficient pressure to lift the heavy inverted cap and permit the intensely cold air to flow out into the vacuum space of the after-cooler, and thence through the spiral space of the liquefier. At the same time a portion of the cold air will pass through the coiled siphon tube and out the draw-off valve. Soon the parts of the after-cooler become sufficiently chilled, and the liquid air, passing through

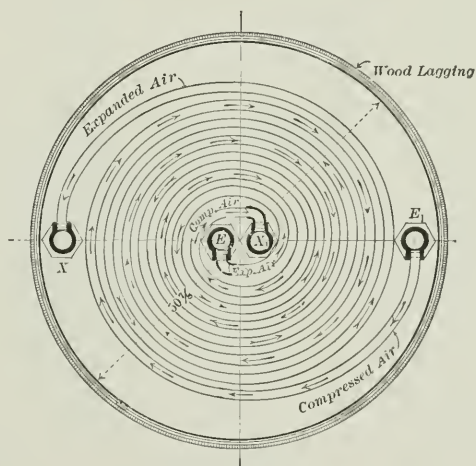


FIG. 544.—PLAN OF BRINE TANK.

the lower valve, remains in a liquid state. The heavy cap is so proportioned that there is a pressure of about 6 pounds per square inch on the liquid surface, and this is sufficient to force the liquid air through the siphon tube and out of the faucet. We then have the following condition of affairs:

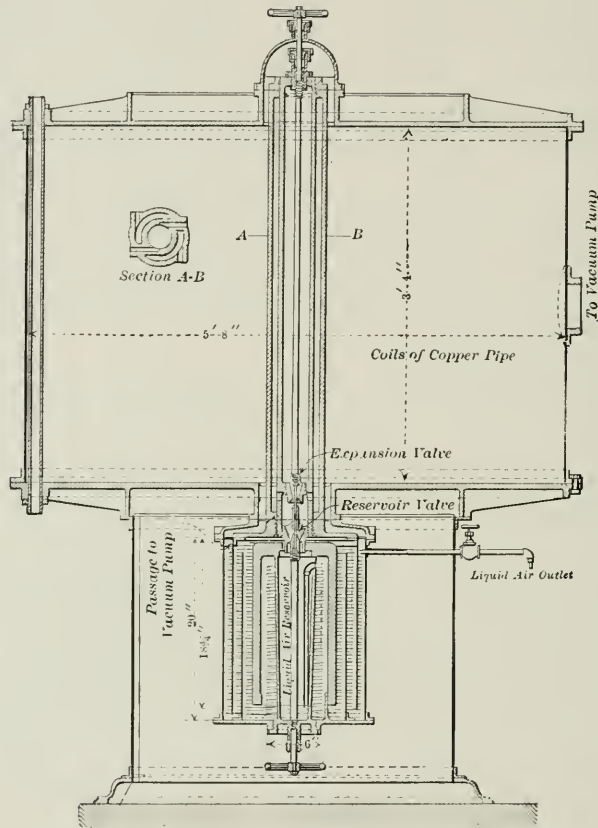


FIG. 545.—SECTION. BRINE TANK, EXPANSION VALVE, LIQUEFING CHAMBER, AND LIQUID-AIR RESERVOIR OR AFTER-COOLER.

The reservoir is partially filled with liquid air, as is also the coils of the after-cooler, and the space surrounding the tubes is constantly being exhausted, so that whatever liquid air or vapor air may spill over when the inverted cap lifts, is instantly evaporated in and around these filled tubes, thus further reducing the temperature of the air about to be drawn off; the vacuum

spiral space surrounding the tubes of the liquefier is constantly having the intensely cold evaporated air passing through it, and the temperature of the whole apparatus is therefore being gradually reduced toward some minimum, which so far as present indications go is remarkably near absolute zero.

One of the problems to be solved, before liquid air can be of any great commercial value, is some method of carrying and storing the material so that it can be retained in a liquid form. The company has endeavored to perfect this feature in a practical and business-like way.

The result of the company's efforts in this line is the construction of metallic tanks of various sizes up to 40 gallons capacity, in which an inner metallic vessel is inclosed except for a small offset pressure-gauge tube, and the larger opening constituting at the same time the filling tube and the relief valve. Surrounding this is a second vessel, in its turn surrounded by some non-conducting material such as corn pith, excelsior, granulated cork, or the like, contained in a wicker basket. The inner tank being filled with liquid air, the relief valve automatically opens slightly from time to time, as the pressure exceeds about 6 pounds, and permits the escape of the cold air into the space between the two metallic tanks. This forces the warmer air out through the bottom of the tank and maintains a very cold blanket of air between the liquid air and the exterior insulating casing; smaller and cheaper forms are made by using an open inner vessel made of wood pulp similar to the well-known one-piece water-buckets. These are surrounded by wire netting held away by small wooden strips. The vessel is then put in a wicker basket, packed about with some insulating material as in the former case, and is provided with a wooden cover which rests on the wire netting and forms an air space.

Still another form consists of two metallic spheres, between which is a third moulded cork sphere held away from the others. Both the inner and outer spheres are provided with separate

relief valves, so that when the pressure exceeds a certain set amount the inner valve lifts and, one might say, exhales into the space between the inner and the cork sphere. The cold air gradually works outward through the cork, becoming warmer as it progresses. Finally it reaches the space between the cork shell and the outer metal casing and accumulates until the pressure is sufficient to lift the second valve, when it passes into the surrounding atmosphere.

While the company has devoted its chief endeavors to the process of liquid air manufacture and transportation, it has also paid some attention to the possible applications of liquid air. One which is of especial interest in the summer days is the operation of a cooling fan by compressed air obtained from volatilizing liquid air. The liquid is held in a suitable receptacle, while a coil connected with this receptacle constitutes a vaporizer and heater utilizing the heat of the atmosphere. The fan is revolved by a small turbine driven by the air under pressure, which, as it escapes from the motor, is caught by the fan blades and whirled forward in the current of air. In this way not only is the air in a room kept in constant motion, but it is continually cooled and freshened by the addition of the cold exhaust air of the motor.

Chapter XXXVI.

PATENTS

PATENTS.

ISSUED BY THE UNITED STATES PATENT OFFICE ON COMPRESSED
AIR AND ITS APPLIANCES, FROM 1875 TO JULY 1, 1901.

1875.

Air Engine—Rider.....	167,568
Air Engine—Rider.....	158,525
Air Engine—Riley.....	165,027
Air Compressor—Bailey.....	161,090
Air Compressor—Corobbi & Bel- lini.....	159,075
Air Brake—James.....	165,235
Air Brake—Jones.....	166,386
Air Brake—Ladd.....	165,337
Air Brake—Moscowitz.....	166,026
Air Brake—Perrine.....	166,404
Air Brake—Perrine.....	166,405
Air Brake—Perrine.....	166,406
Air Brake—Perrine.....	169,575
Air Brake—Westinghouse.....	162,465
Air Compressor—Reynolds.....	160,956
Air Engine—Connolly.....	164,809

1876.

Air Engine—Schmacke.....	184,913
Air Compressor—Crocker.....	176,931
Air Compressor—Fulton.....	177,495
Air Compressor—Hill.....	171,805
Air Compressor—Laurence.....	172,751
Air Compressor—Manz.....	176,795
Air Brake—Chadwick.....	180,460
Air Brake—Reniff.....	183,206
Air Brake—Westinghouse.....	175,886
Air Brake—Westinghouse.....	180,179
Air Compressor—Sawtell.....	183,596
Air Compressor—Seal.....	174,860
Air Compressor—Seal.....	182,333
Air Compressor—Sturgeon.....	180,958
Air Compressor—Tallman.....	176,096

1877.

Air Compressor—Babbitt.....	198,067
Air Compressor—Clayton.....	186,306
Air Compressor—Garrison.....	186,336
Air Brake—Green et al.....	198,015
Air Brake—Stevens.....	191,261
Air Compressor—Reynolds.....	187,906
Air Compressor—Root.....	196,253
Air Engine—Allen.....	193,631
Air Engine—Davy.....	186,119
Air Engine—Hock & Martin.....	190,490

1878.

Air Engine—McKinley.....	206,597
Air Engine—Rider.....	206,356
Air Engine—Ward.....	198,827
Air Compressor—Doremus.....	207,954
Air Compressor—Dreyfus.....	200,901
Air Compressor—Frizell.....	199,819
Air Brake—Knapp.....	204,440
Air Brake—Maxwell.....	207,126
Air Brake—Newton.....	202,368
Air Brake—Prince.....	204,914
Air Brake—Raoul.....	203,647
Air Compressor—Springer.....	211,062

1879.

Air Engine—Rider.....	220,309
Air Engine—Sherrill.....	213,783
Air Compressor—Clayton.....	222,014
Air Compressor—Clayton.....	220,123
Air Compressor—Gardner.....	221,802
Air Compressor—Harvey.....	211,570
Air Compressor—Jackson.....	218,029
Air Compressor—Johnston.....	221,318
Air Compressor—Moore.....	216,211
Air Brake—Osgood.....	212,972
Air Brake—Schultz.....	220,178
Air Brake—Westinghouse.....	214,603
Air Compressor—Pitchford.....	215,540
Air Compressor—Spencer.....	214,465
Air Compressor—Tatham.....	222,802
Air Compressor—Thomas.....	217,834
Air Compressor—Treat.....	221,126
Air Engine—Eckart.....	216,563
Air Engine—Hardie & James.....	216,611
Air Engine—Mathes.....	214,050

1880.

Air Engine—Presbrey.....	231,446
Air Engine—Thuemmler.....	232,660
Air Engine—Thuemmler.....	233,125
Air Engine—Woodbury et al.....	228,712
Air Engine—Woodbury et al.....	228,713
Air Engine—Woodbury et al.....	228,714
Air Engine—Woodbury et al.....	228,715
Air Engine—Woodbury et al.....	228,716
Air Engine—Woodbury et al.....	228,717
Air Compressor—Bois.....	227,877
Air Compressor—Bucill.....	234,751
Air Compressor—Connor & Dods.....	232,939

Air Compressor—Eckart.....	224,081
Air Compressor—Hill.....	229,821
Air Compressor—Lawrence et al.....	226,918
Air Brake—Glenn.....	234,179
Air Brake—Hall.....	231,311
Air Brake—Loughridge.....	234,134
Air Compressor—Parkinson.....	225,151
Air Compressor—Pitchford.....	233,432
Air Compressor—Richmann.....	229,468
Air Compressor—Rix.....	235,296
Air Compressor—Rix.....	235,816
Air Compressor—Sergeant.....	233,881
Air Compressor—Stockman.....	234,733
Air Engine—Beaumont.....	232,438
Air Engine—Ericsson.....	226,052
Air Engine—Hill.....	229,821

1881.

Air Compressor—Allen.....	237,359
Air Compressor—Allen.....	237,360
Air Compressor—Boerner.....	239,310
Air Compressor—Buell.....	246,657
Air Compressor—Clayton.....	241,930
Air Compressor—Cushier.....	236,992
Air Compressor—Freeman.....	238,225
Air Compressor—Fitzpatrick.....	238,374
Air Compressor—Hill.....	244,127
Air Compressor—Hill.....	244,128
Air Compressor—Hill.....	237,274
Air Compressor—Hill.....	243,257
Air Compressor—Hudson.....	241,984
Air Compressor—Livingston.....	242,008
Air Compressor—Mayrhofer.....	236,713
Air Brake—Eames.....	241,323
Air Brake—Eames.....	241,325
Air Brake—Lorraine.....	246,166
Air Brake—Westinghouse.....	243,415
Air Brake—Westinghouse.....	245,109
Air Brake—Westinghouse.....	245,110
Air Compressor—Quinn.....	236,455
Air Compressor—Robinson & Ki- ser.....	248,218
Air Engine—Lyman.....	236,954

1882.

Air Engine—Reynolds.....	262,119
Air Compressor—Babcock.....	253,830
Air Compressor—Baker.....	259,741
Air Compressor—Beers.....	268,854
Air Compressor—Bols.....	259,799
Air Compressor—Bradley.....	254,915
Air Compressor—Hill.....	261,606
Air Compressor—Hill.....	261,605
Air Compressor—Manning.....	256,232
Air Compressor—Mayrhofer.....	261,560
Air Compressor—Monson.....	257,885
Air Brake—Brockway et al.....	264,617
Air Brake—Ford.....	266,684
Air Brake—Hanscom.....	265,671
Air Brake—Van Dusen.....	269,747
Air Compressor—Overton.....	263,206
Air Compressor—Overton.....	263,207
Air Compressor—Rand.....	255,116
Air Compressor—Reynolds.....	262,119

Air Compressor—Sergeant.....	264,775
Air Compressor—Smith.....	269,730
Air Compressor—Wang.....	255,222
Air Compressor—Wang.....	255,901
Air Compressor—Wang.....	262,157

1883.

Air Engine—Nash.....	278,257
Air Engine—Wilcox.....	289,481
Air Engine—Wilcox.....	289,482
Air Compressor—Babcock.....	280,997
Air Compressor—Babcock.....	287,258
Air Compressor—Bennett.....	283,955
Air Compressor—Bicknell.....	273,014
Air Compressor—Cullingworth.....	287,104
Air Compressor—Fox.....	285,742
Air Compressor—Freeman.....	290,764
Air Compressor—Honigman.....	288,435
Air Compressor—Lawler.....	272,711
Air Brake (re-issue)—Ford.....	10,298
Air Brake—Reilly.....	290,269
Air Brake—Thayer et al.....	283,534
Air Brake—Westinghouse.....	270,528
Air Compressor—Moore.....	285,297
Air Compressor—Reynolds.....	272,771
Air Compressor—Sturgeon.....	275,959
Air Engine—Boynton.....	289,967
Air Engine—Cook.....	271,040
Air Engine—Cook.....	272,656
Air Engine—Eimecke.....	270,036
Air Engine—McDonough.....	278,446

1884.

Air Engine—Robinson.....	309,163
Air Engine—Stevens.....	305,114
Air Engine—Wilcox (re issue)...	10,486
Air Engine—Wilcox (re-issue)...	10,529
Air Compressor—Allen.....	299,314
Air Compressor—Bristin.....	302,978
Air Compressor—Chichester.....	308,061
Air Compressor—Cullen.....	307,442
Air Compressor—Ehlers.....	301,348
Air Compressor—Hill.....	292,814
Air Compressor—Krutsch.....	302,206
Air Brake—Diekson.....	306,140
Air Brake—Flad.....	296,546
Air Brake—Flad.....	307,535
Air Brake—Flad.....	307,536
Air Brake—Green.....	309,845
Air Brake—Magowan.....	293,481
Air Brake—Mark.....	307,561
Air Brake—Paradise.....	293,774
Air Brake—Sjogren.....	300,401
Air Brake—Sloan.....	307,344
Air Brake—Willis.....	303,777
Air Compressor—Moore.....	309,642
Air Compressor—Norris.....	310,148
Air Compressor—Pfanne.....	295,800
Air Engine—Baldwin.....	292,400
Air Engine—Bausman.....	299,325
Air Engine—Cramer.....	294,369
Air Engine—Eteve & DeBraan.....	309,835
Air Engine—Graham.....	302,246
Air Engine—Leavitt.....	307,312
Air Engine—Maxim.....	293,185

1885.

Air Engine—McTighe.....	321,739
Air Engine—Pollock.....	316,656
Air Engine—Shilling.....	320,182
Air Engine—Wilcox.....	332,312
Air Engine—Wood.....	324,510
Air Engine—Woodbury et al.....	324,062
Air Engine—Woodbury et al.....	331,359
Air Engine—Woodbury et al.....	331,361
Air Engine—Woodbury et al.....	324,060
Air Engine—Woodbury et al.....	324,061
Air Engine—Woodbury et al.....	325,640
Air Engine—Woodbury et al.....	327,748
Air Compressor—Bolton.....	314,218
Air Compressor—Corey.....	311,106
Air Compressor—Erwin.....	329,377
Air Compressor—Erwin.....	333,208
Air Compressor—Fox.....	321,206
Air Compressor—Fox.....	321,207
Air Compressor—Leavitt.....	320,482
Air Brake—Bass.....	312,245
Air Brake—Hanscom.....	326,646
Air Brake—Hopper.....	321,971
Air Brake—McKinney.....	311,196
Air Brake—Sloan.....	327,027
Air Brake—Sloan.....	330,164
Air Compressor—Monson.....	328,598
Air Engine—Bolton.....	314,218
Air Engine—Bausman.....	313,646
Air Engine—Coffield.....	322,796
Air Engine—Colman.....	317,093
Air Engine—Colman.....	317,628
Air Engine—Corey.....	311,106
Air Engine—Hanover.....	310,419
Air Engine—Hurd.....	325,805
Air Engine—Leavitt.....	321,985
Air Engine—Limpus.....	329,914

1886.

Air Engine—Rider.....	345,450
Air Engine—Rider.....	353,004
Air Engine—Serdinko.....	335,388
Air Compressor—Chichester.....	333,994
Air Compressor—Cullingworth.....	355,002
Air Compressor—Depp.....	333,613
Air Compressor—Dow.....	341,099
Air Compressor—Erwin.....	340,496
Air Compressor—Fevrot.....	336,224
Air Compressor—Harrold.....	345,969
Air Compressor—Hugentobler.....	342,798
Air Compressor—Johnson.....	349,954
Air Compressor—McLean.....	341,673
Air Brake—Easton.....	354,014
Air Brake—Goode.....	352,446
Air Brake—Haberkorn.....	335,446
Air Brake—Hollerith.....	334,020
Air Brake—Hollerith.....	334,021
Air Brake—Hollerith.....	334,022
Air Brake—Kneeland.....	351,383
Air Brake—Melson.....	352,927
Air Brake—Perkins.....	345,537
Air Brake—Pickering.....	334,466
Air Brake—Wisner.....	335,094
Air Compressor—Swartz.....	342,310

Air Compressor—Thomas.....	337,209
Air Engine—Babcock.....	334,152
Air Engine—Babcock.....	334,153
Air Engine—Babcock.....	334,154
Air Engine—Lachmann.....	333,644

1887.

Air Engine—McKinley.....	356,146
Air Engine—McKinley.....	356,147
Air Engine—Philpott.....	359,282
Air Engine—Tasker.....	364,451
Air Compressor—Chichester.....	370,376
Air Compressor—Cummings.....	363,509
Air Brake—Bass.....	358,142
Air Brake—Carpenter.....	359,953
Air Brake—Hanscom.....	369,057
Air Brake—Westinghouse.....	360,070
Air Compressor—Strange.....	373,419
Air Engine—Baldwin & Bradford.....	355,633
Air Engine—Close.....	366,204

1888.

Air Engine—Rider.....	393,663
Air Engine—Rider.....	393,723
Air Engine—Winchell.....	381,313
Air Compressor—Chamberlain.....	376,141
Air Compressor—Cullingworth.....	377,481
Air Compressor—Dean.....	380,195
Air Compressor—Erwin.....	382,760
Air Compressor—Forster.....	375,929
Air Compressor—Forster.....	376,589
Air Compressor—Forster.....	384,356
Air Compressor—Hunter.....	392,611
Air Compressor—Keenan.....	384,529
Air Compressor—McKim.....	375,761
Air Brake—Andrews.....	385,224
Air Brake—Boluss.....	382,749
Air Brake—Carpenter.....	378,657
Air Brake—Dixon.....	382,031
Air Brake—Dixon.....	389,643
Air Brake—Guels.....	384,686
Air Brake—Guels.....	384,687
Air Brake—Harvey.....	378,365
Air Brake—Lansberg.....	386,640
Air Brake—Lansberg.....	392,872
Air Brake—Lehy.....	381,392
Air Brake—Lewis.....	383,819
Air Brake—Park.....	385,198
Air Brake—Park.....	393,784
Air Brake—Solano.....	376,970
Air Brake—Solano.....	378,628
Air Brake—Solano.....	382,667
Air Brake—Solano.....	387,018
Air Brake—Williams.....	393,950
Air Compressor—Nosbaume.....	393,172
Air Compressor—Pitt.....	386,028
Air Compressor—Reynolds.....	378,336
Air Engine—Bair.....	389,045
Air Engine—Clark.....	386,454
Air Engine—Genty.....	387,063

1889.

Air Engine—Schmid & Beckfeld.....	403,294
Air Engine—Stevens.....	414,173

Air Engine—Woodbury et al.	404, 237
Air Engine—Wright	408, 784
Air Compressor—Cummings	412, 474
Air Compressor—Davey	409, 773
Air Compressor—Fitzpatrick	402, 517
Air Compressor—Funk	417, 717
Air Compressor—Guthrie	417, 482
Air Brake—Boluss	414, 138
Air Brake—Boluss	398, 310
Air Brake—Collins	400, 638
Air Brake—Collins	400, 639
Air Brake—Dixon	402, 418
Air Brake—Dixon	412, 168
Air Brake—Dixon	418, 506
Air Brake—Daellenbach	415, 162
Air Brake—Haberkorn	398, 829
Air Brake—Haberkorn	413, 253
Air Brake—Holleman	405, 705
Air Brake—Lansberg	415, 513
Air Brake—Lansberg	415, 514
Air Brake—Lansberg	415, 515
Air Brake—Lansberg	415, 516
Air Brake—Lansberg	415, 517
Air Brake—Lapish	399, 420
Air Brake—Lewis	410, 288
Air Brake—Marsh	396, 284
Air Brake—Massey	414, 717
Air Brake—Maxwell	405, 968
Air Brake—Norris	413, 205
Air Brake—Park	407, 445
Air Brake—Pitchard	410, 922
Air Brake—Pitchard et al.	399, 158
Air Brake—Pitchard et al.	399, 157
Air Brake—Rymer	416, 953
Air Brake—Solano	405, 855
Air Brake—Solano	406, 006
Air Compressor—Sergeant	415, 822
Air Engine—Baldwin	404, 818
Air Engine—Humes	400, 850

1890.

Air Engine—Brock	434, 422
Air Engine—Eastman	443, 641
Air Engine—Ericsson	431, 792
Air Engine—Harder	438, 251
Air Engine—Metzing	441, 103
Air Engine—McCallia	420, 824
Air Engine—McTighe	429, 281
Air Engine—McTighe	429, 282
Air Engine—McTighe	429, 283
Air Engine—Rogers	427, 911
Air Engine—Schmid & Beckfeld	421, 525
Air Engine—Vivian	437, 320
Air Compressor—Eloheimo	435, 034
Air Brake—Boluss	435, 791
Air Brake—Burbank et al.	428, 299
Air Brake—Daellenbach	442, 019
Air Brake (re-issue)—Guels	11, 070
Air Brake—Guillemet	437, 300
Air Brake—Harris	442, 621
Air Brake—Hogan	433, 127
Air Brake—Hogan	433, 594
Air Brake—Hogan	433, 595
Air Brake—Hopper	430, 024
Air Brake—Lansberg	439, 528

Air Brake—Maher	433, 737
Air Brake—Martin	437, 218
Air Brake—Roberts	433, 040
Air Brake—Robinson	437, 800
Air Brake—Stewart	420, 121
Air Brake—Schroyer	426, 144
Air Brake—Walker	438, 038
Air Brake—Westinghouse	421, 641
Air Brake—Williams	441, 526
Air Brake—Williams	431, 303
Air Brake—Williams	431, 790
Air Brake (re-issue)—Williams	11, 124
Air Brake—Williams	431, 304
Air Compressor—Hill	439, 876
Air Compressor—Massey	433, 951
Air Compressor—Rand & Halsey	421, 611

1891.

Air Engine—Benster	463, 092
Air Engine—Bergman	463, 025
Air Engine—Chapman	447, 066
Air Engine—Griswold	455, 201
Air Engine—Hall	457, 272
Air Engine—Hall	457, 273
Air Engine—Jefferson	464, 364
Air Engine—Robinson	445, 904
Air Engine—Rusk	458, 070
Air Compressor—Clark	453, 374
Air Brake—Barnes et al.	462, 193
Air Brake (re-issue)—Bayley	11, 145
Air Brake—Bothwell	456, 247
Air Brake—Beery	452, 334
Air Brake—Dodd	462, 966
Air Brake—Hogan	447, 731
Air Brake—Hopper	458, 626
Air Brake—James	447, 236
Air Brake—James	461, 243
Air Brake—Lansberg	445, 899
Air Brake—Marshall	456, 199
Air Brake—Massey	451, 409
Air Brake—Massey	447, 783
Air Brake—Riggs	457, 215
Air Brake—Slater	452, 942
Air Brake—Waite	463, 085
Air Brake—Westinghouse	448, 827
Air Brake—Westinghouse et al.	461, 779
Air Brake—Wisner	446, 908
Air Compressor—Hill	448, 859
Air Compressor—Hill	452, 132
Air Compressor—Hill	454, 590
Air Compressor—Hill	463, 386
Air Compressor—Nordberg	458, 975
Air Compressor—Phillips	452, 283
Air Compressor—Richards	462, 727
Air Compressor—Richmann	459, 527
Air Compressor—Richmann	462, 453
Air Compressor—Sergeant	447, 910
Air Compressor—Sergeant	456, 165

1892.

Air Compressor—Avery	482, 775
Air Compressor—Beck	476, 723
Air Compressor—Dillenburg	481, 850
Air Compressor—Dunn	473, 302
Air Compressor—Farrell	479, 260

Air Compressor—Fasoldt.....	481,527
Air Compressor—Guillemet.....	482,040
Air Compressor—Haines.....	470,934
Air Compressor—Haines.....	480,193
Air Compressor—Hanford.....	474,296
Air Compressor—Hanston & Bar-	
dan.....	471,766
Air Brake—Beery.....	485,365
Air Brake—Coates.....	467,920
Air Brake—Coates.....	467,921
Air Brake—Corporan.....	483,802
Air Brake—Carpenter.....	479,736
Air Brake—Duval.....	486,703
Air Brake—Dunn.....	473,302
Air Brake—Fahmney.....	485,182
Air Brake—Guillemet.....	482,040
Air Brake—Hamney.....	476,880
Air Brake—Harris.....	472,190
Air Brake—Hayden.....	481,651
Air Brake—Hogan.....	473,839
Air Brake—Hogan.....	482,058
Air Brake—Knudsen.....	468,887
Air Brake—McNulta.....	471,801
Air Brake—Marble.....	484,034
Air Brake—Mills.....	476,546
Air Brake—Pelton.....	482,382
Air Brake—Shortt.....	469,176
Air Brake—Sileock.....	468,701
Air Compressor—Henderson &	
Scultz.....	475,111
Air Compressor—Hutchinson.....	481,143
Air Compressor—O'Brien.....	477,381
Air Compressor—Perry.....	485,881
Air Compressor—Sherman.....	475,251
Air Compressor—Teal.....	474,034

1893.

Air Engine—Durand.....	497,048
Air Engine—Field.....	506,486
Air Engine—Hauser & Whittaker.....	489,148
Air Engine—Martin.....	500,340
Air Engine—Muselman.....	502,860
Air Engine—Schon.....	508,990
Air Engine—Smith.....	491,859
Air Compressor—De Laval.....	511,086
Air Compressor—Fogg.....	493,263
Air Compressor—Gustafson.....	509,220
Air Brake—Barber.....	494,772
Air Brake—Dean.....	511,071
Air Brake—Duval.....	510,635
Air Brake—Duval.....	510,870
Air Brake—Dunn.....	489,527
Air Brake—Erbody.....	510,594
Air Brake—Hayden.....	509,898
Air Brake—Higgins.....	503,083
Air Brake—Hinckley.....	508,421
Air Brake—Keywood.....	500,910
Air Brake—Massey.....	501,016
Air Brake—Masterman.....	504,227
Air Brake—Parke et al.....	506,185
Air Brake—Pinkston.....	501,359
Air Brake—Pool et al.....	499,582
Air Brake—Shallenberger.....	506,739
Air Brake—Sennett et al.....	489,763
Air Compressor—Knoche.....	508,225

Air Compressor—Perry.....	498,989
Air Compressor—Quast.....	501,046
Air Compressor—Schutzinger.....	508,150
Air Compressor—Walker.....	491,232

1894.

Air Engine—Depp.....	521,762
Air Engine—Rogers.....	511,969
Air Engine—Stewart.....	519,977
Air Compressor—Babcock.....	523,064
Air Compressor—Birner & Mes-	
sing.....	520,405
Air Compressor—Brotherhood.....	515,282
Air Compressor—Champ.....	513,556
Air Compressor—Champ.....	515,516
Air Compressor—Champ.....	523,830
Air Compressor—Flood.....	519,383
Air Compressor—Griffiths et al.....	530,335
Air Brake—Bayley.....	528,712
Air Brake—Brown.....	520,391
Air Brake—Barbridge et al.....	526,178
Air Brake—Bishop.....	531,584
Air Brake—Clark.....	522,825
Air Brake—Clifton.....	531,100
Air Brake—Edwards.....	527,838
Air Brake—Eldridge.....	527,327
Air Brake—Fox.....	530,937
Air Brake—Fox.....	530,938
Air Brake—Fox.....	530,939
Air Brake—Haberkorn.....	531,181
Air Brake—Harris.....	515,220
Air Brake—Harris.....	516,202
Air Brake—Hunt.....	529,270
Air Brake—James.....	524,990
Air Brake—Jeffries.....	513,267
Air Brake—Knudsen.....	525,686
Air Brake—Lausberg.....	516,936
Air Brake—Lencke.....	517,955
Air Brake—Lencke et al.....	517,954
Air Brake—McCarty.....	529,290
Air Brake—Mable.....	526,189
Air Brake—Mills.....	537,784
Air Brake—O'Hara.....	519,681
Air Brake—Rothschild.....	515,616
Air Brake—Rothschild.....	515,617
Air Brake—Richardson.....	513,145
Air Brake—Schenck.....	524,073
Air Brake—Schenck.....	531,137
Air Brake—Shortt.....	530,904
Air Brake—Stewart.....	517,250
Air Brake—Vorhees.....	524,050
Air Brake—Vorhees.....	525,876
Air Brake—Willson.....	516,692
Air Compressor—North.....	527,248
Air Compressor—Schutz-Hender-	
son.....	517,628
Air Compressor—Sergeant.....	514,839
Air Compressor—Sergeant.....	530,662

1895.

Air Engine—Anderson.....	537,517
Air Engine—Bramwell.....	543,462
Air Engine—Denney.....	538,068
Air Engine—Fletcher & Hug-	
gings.....	547,718

Air Engine—Parsons.....	549,741	Air Compressor—Du Faur	561,160
Air Engine—Sherman.....	535,602	Air Compressor—Elliott.....	568,433
Air Compressor—Blake.....	534,192	Air Compressor—Githens.....	563,477
Air Compressor—Champ.....	544,456	Air Compressor—Guyser.....	560,987
Air Compressor—Champ.....	544,457	Air Brake—Beemer.....	564,863
Air Compressor—Champ.....	544,458	Air Brake—Brookmire.....	558,670
Air Compressor—Champ.....	544,459	Air Brake—Custer.....	553,481
Air Compressor—Champ.....	547,768	Air Brake—Custer.....	553,482
Air Compressor—Chaquette.....	548,800	Air Brake—Dunn.....	553,517
Air Compressor—Clayton.....	534,814	Air Brake—Dunn.....	567,024
Air Compressor—Duffy.....	547,338	Air Brake—Fenley et al.....	553,498
Air Compressor—Durand.....	550,163	Air Brake—Genett.....	556,815
Air Compressor—Griffiths et al.....	547,882	Air Brake—Glass.....	569,915
Air Brake—Clarke.....	549,703	Air Brake—Graebing.....	569,823
Air Brake—Comess.....	540,539	Air Brake—Guillemet.....	571,115
Air Brake—Christensen.....	534,813	Air Brake—Guillemet.....	571,116
Air Brake—Dunn.....	546,510	Air Brake—Hall.....	574,062
Air Brake—French.....	533,286	Air Brake—Harris.....	571,662
Air Brake—Harris.....	544,253	Air Brake—Herder.....	558,174
Air Brake—Harris.....	547,253	Air Brake—Herbert.....	572,009
Air Brake—Hogan.....	546,448	Air Brake—High.....	555,809
Air Brake—Hogan.....	546,449	Air Brake—Howe et al.....	567,476
Air Brake—Hogan.....	551,440	Air Brake—June.....	570,483
Air Brake—Hogan.....	551,767	Air Brake—Lee.....	557,511
Air Brake—Humbert et al.....	539,430	Air Brake—Lee.....	557,512
Air Brake—Hunt.....	545,295	Air Brake—Lee.....	557,513
Air Brake—Jeffries.....	550,346	Air Brake—Lee.....	557,514
Air Brake—Massey.....	535,844	Air Brake—Lee.....	557,515
Air Brake—Massey.....	537,057	Air Brake—Lindsey.....	561,596
Air Brake—Schenck.....	532,914	Air Brake—Mable.....	572,553
Air Brake—Sennett.....	536,000	Air Brake—Marshall.....	560,730
Air Brake—Shortt.....	538,547	Air Brake—Noyes.....	553,565
Air Brake—Shortt.....	538,551	Air Brake—Noyes.....	564,389
Air Brake—Shortt.....	538,544	Air Brake—Noyes.....	571,095
Air Brake—Shortt.....	538,549	Air Brake—Noyes.....	571,786
Air Brake—Shortt et al.....	538,546	Air Brake—Omick.....	563,612
Air Brake—Steedman.....	542,948	Air Brake—Park.....	561,811
Air Brake—Thompson.....	545,749	Air Brake—Reyburn.....	568,923
Air Brake—Tower et al.....	538,299	Air Brake—Rogers et al.....	553,294
Air Brake—Trott.....	536,002	Air Brake—Thompson.....	571,708
Air Brake—Wessels et al.....	548,335	Air Brake—Walker et al.....	569,258
Air Brake—Wheeler.....	546,835	Air Brake—Westinghouse.....	557,464
Air Brake—White.....	538,002	Air Brake—Willets.....	561,301
Air Compressor—Kalthoff.....	551,549	Air Brake—Zenke.....	571,736
Air Compressor—Keenan.....	547,519	Air Compressor—Hill.....	571,971
Air Compressor—Lowe & Guyser.....	534,399	Air Compressor—Liming.....	569,929
Air Compressor—Moyer.....	541,979	Air Compressor—Merritt.....	562,475
Air Compressor—Noack.....	550,352	Air Compressor—Nichols.....	555,178
Air Compressor—Pedrick.....	544,548	Air Compressor—Noyes.....	563,794
Air Compressor—Stambaugh.....	548,399	Air Compressor—Pendleton.....	561,126
Air Compressor—Taylor.....	543,410	Air Compressor—Reynolds.....	572,377
Air Compressor—Taylor.....	543,411	Air Compressor—Roberts.....	572,314
Air Compressor—Taylor.....	543,412	Air Compressor—Sergeant.....	568,804
		Air Compressor—Shaw.....	552,590
		Air Compressor—Smith.....	572,383
		Air Compressor—Underwood.....	558,125

1896.

Air Engine—Bercher.....	558,475
Air Engine—Coon.....	555,929
Air Engine—Good.....	560,707
Air Engine—Good & Marichal.....	558,944
Air Engine—Mihlsbach & Groeschell.....	566,785
Air Engine—Walling.....	565,191
Air Compressor—Champ.....	570,540
Air Compressor—Chaquette.....	565,429
Air Compressor—Clark.....	558,041

1897.

Motor Car—R. Hardie.....	584,146
Air Compressor—L. T. Dyer.....	585,090
Pneumatic Despatch—B. C. Bacheller.....	585,498
Air Spray—John Black.....	585,503
Air Brake—E. A. Trapp.....	585,927

Compressor and Cooler—John Flindall.....	585,955
Air Compressor—W. H. Knight.....	586,100
Air Motor—J. H. Hoadley.....	586,127
Pneumatic Sole—Julia F. Bascom.....	586,155
Air Compressor—Alfred Shedlock.....	586,669
Pneumatic Press—P. C. Blaisdell.....	586,946
Air Compressor—I. H. Spencer.....	588,296
Hot-Air Motor—W. Trehella.....	588,509
Air Compressor—E. C. Nichols.....	589,190
Water Elevator—John Hass.....	588,825
Pneumatic Conveyor—A. P. Heslop.....	588,908
Valve—James Clayton.....	587,704
Air Pump—H. S. Bills.....	587,638
Railway Switch—Johnson & McKelthen.....	590,153
Straw Stacker—L. D. Parmley.....	589,853
Pneumatic Motive Power—L. H. Meyer.....	590,686
Pneumatic Tool—F. E. Hartham.....	590,661
Air or Gas Compressor—S. S. Miles.....	591,137
Pneumatic Drill—J. H. Manning.....	591,284
Pneumatic Motor—G. W. Smith.....	591,018
Water-Elevator—P. S. A. Bickel.....	591,029
Pneumatic Hammer—C. H. Johnson.....	592,116
Air Compressor—E. Hill.....	593,049
Pneumatic Painting Apparatus—A. Fisher.....	593,013
Pneumatic Water-Raising Device—E. Pitcher.....	593,431
Pneumatic Motor—F. W. Hedge-land.....	593,655
Pneumatic Motor—T. P. Brown.....	594,891
Air-Controlling Device—A. Roesch.....	595,654
Pneumatic Conveyor—S. H. Jones.....	596,211
Dry Kiln—Franklin Kirk.....	596,212
Pneumatic Stacker—G. W. Quinn.....	596,307
Drying Apparatus—McClatchey & Krum.....	596,175
Pneumatic Despatch Tube—C. F. Pike.....	595,890
Air Pump or Compressor—L. R. Alberger.....	595,429
Air Engine—Anderson & Erickson.....	579,670
Air Engine—Barbour & Hansen.....	591,584
Air Engine—Berry.....	582,257
Air Engine—Bole.....	592,688
Air Engine—Gibbs.....	592,246
Air Engine—Goth.....	580,600
Air Engine—Parke.....	594,901
Air Engine—Reediger.....	579,654
Air Engine—Weimer.....	577,568
Air Compressor—Crabtree.....	594,524
Air Compressor—Griffiths et al.....	576,364
Air Brake—Boyden.....	583,278
Air Brake—Boyden.....	583,279
Air Brake—Buckpitt.....	589,957
Air Brake—Bragg et al.....	593,531
Air Brake—Bentley.....	574,656
Air Brake—Commess.....	587,519
Air Brake—Corrington.....	591,464
Air Brake—Dunn.....	577,425
Air Brake—Fish.....	593,996
Air Brake—Gunckel.....	582,391
Air Brake—Hogan.....	574,866
Air Brake—Hunt.....	581,912
Air Brake—McIntosh.....	589,265
Air Brake—Nellis et al.....	594,033
Air Brake—Omick.....	588,913
Air Brake—Redfern.....	584,705
Air Brake—Shearwood.....	574,498
Air Brake—Shortridge.....	578,168
Air Brake—Westinghouse et al.....	592,461
Air Brake—Winters.....	594,238
Air Compressor—Perine.....	580,714
Air Compressor—Sergeant.....	579,775
Air Compressor—Tonnes.....	576,920
Air or Gas Compressor—J. Crab-tree.....	594,524
1898.	
Air Lift Pump—W. L. Saunders.....	567,023
Compressed-Air Apparatus—J. McIntyre.....	596,822
Drier—K. S. Blanchard.....	596,470
Grain Drier—W. E. Ellis.....	596,655
Refrigerator—J. H. Barrett.....	596,967
Air Compressor—T. H. Roberts.....	597,233
Lumber Drier—H. J. Morton.....	597,543
Air Valve—S. C. Arnold.....	597,666
Air Brake—H. F. Noyes.....	599,348
Air Compressor—J. H. Hoadley.....	598,149
Governor Valve, Compressor—Christensen.....	598,283
Pneumatic Spring—W. Kowaleff.....	598,102
Air Disc-Brake—M. E. Company.....	598,766
Air Cleaning, Cooling Device—McCreery.....	599,080
Pneumatic Conveyor—S. C. Davidson.....	599,055
Pneumatic Spring—E. L. Egger.....	598,982
Pneumatic Stacker—G. W. Wood.....	599,279
Street-Car Air Brake—C. A. Gray.....	599,421
Drier—A. S. Livengood.....	599,509
Fruit Drier—Steevens & Steevens.....	599,647
Air Brake—Noyes.....	599,349
Air Compressor—P. Cramer.....	600,258
Air Compressor (re-issue)—F. M. Graham.....	11,654
Compressor—J. Stumpf.....	600,626
Hot-Air Compressor—Anderson & Erickson.....	601,031
Air Brake—W. O. Gunckel.....	601,253
Air-Brake Valve—W. O. Gunckel.....	601,252
Pneumatic Hub—W. C. Kone-man.....	599,907
Liquid Distribution—F. M. Griswold.....	599,702
Air Brake—Catlett.....	598,814
Air Brake—Gunckel.....	601,253

- Air Brake—Hamar et al. 600,641
 Air Brake—Kholodowski. 600,537
 Air Brake—Olin. 598,678
 Air Brake—Perkins. 598,887
 Air Brake—Pettengell. 597,220
 Air Brake—Wands. 604,244
 Air Compressor—H. C. Sergeant. 602,877
 Compressed Air—Hammer—J. Schmidt. 602,198
 Valve, Air Compressor—F. Richards. 602,473
 Hydraulic Air Pump—E. H. Weatherhead. 603,242
 Hydraulic Air Compressor—W. F. Stark. 602,247
 Air Brake—J. J. Nef. 602,094
 Air Valve—E. A. Rix. 602,170
 Hot-Air Furnace—J. T. Warren. 601,822
 Air Distributor—J. Jauch. 603,105
 Pneumatic Despatch Tube—H. Clay. 603,174
 Pneumatic Organ—M. Clark. 603,127
 Governor Air Compressor—C. Cummings. 603,425
 Pneumatic Elevator—J. B. Schuman. 603,925
 Pneumatic Despatch—Mathias. 604,405
 Air Brake—W. O. Gunckel. 604,612
 Compressed Air Engine—L. T. Gibbs. 604,745
 Air Compressor—O. H. Bringham. 604,717
 Air Compressor—E. Bottini. 604,962
 Air Brake—W. H. Clowry. 605,394
 Hot-Air Furnace—T. G. Neal. 605,329
 Air Brake—H. S. Park. 605,904
 Air Brake—H. S. Park. 605,905
 Pneumatic Motor—F. W. Hedgeland. 605,876
 Air Compressor—F. Richards. 606,428
 Hydraulic Air Compressor—Noack. 606,732
 Hydraulic Air Compressor—Noack. 606,733
 Air Brake—William Hirst. 607,371
 Air Brake—M. Carrington. 606,708
 Air Brake—L. F. Guillemet. 606,712
 Hot-Air Furnace—H. L. Wingert. 606,752
 Valve-Gear, Air Compressor—Söderholm. 607,195
 Hot-Air Furnace—J. T. & J. K. Brien. 607,793
 Gas Power Process—E. N. Dickerson. 607,655
 Air Brake—C. L. Ansley. 608,095
 Air Brake—Murray Corrington. 608,030
 Air Compressor—C. N. Dutton. 609,087
 Air Compressor—C. N. Dutton. 609,088
 Air Compressor—Heston & Harvison. 608,964
 Air Brake—F. L. Guillemet. 608,599
 Air Brake—F. L. Guillemet. 608,600
 Air Brake—H. S. Parke. 608,621
 Air-Brake—J. J. Nef. 609,041
 Air Brake—J. J. Nef. 609,042
 Pneumatic Despatch Tube—S. R. Gayton. 610,528
 Air-Compressor Inlet-Valve—J. G. Leyner. 610,608
 Tide-Water Air Compressor—Beckers. 610,790
 Pneumatic Motor—F. W. Hedgeland. 611,629
 Locomotive Air Brake—W. P. Alter. 612,149
 Automatic Air Brake—McLaughlin. 612,778
 Air Brake—W. T. Hamar. 613,142
 Air Compressor Governor—Libby. 613,692
 Air Agitator—E. F. Porter. 614,275
 Air Engine—M. Schmidt. 614,992
 Air Brake—J. F. Voorhees. 615,326
 Pneumatic Dry Dock—C. N. Dutton. 615,440
 Air Compressor—W. H. Barr. 615,668
 Pneumatic Gas Lighter—E. Knapp. 615,717
 Air Brake—M. Corrington. 616,288

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- Hydraulic Air Compressor—Sterzing. 618,242
 Hydraulic Air Compressor—Taylor. 618,243
 Air Brake—E. A. Hauerwas. 618,204
 Air Purifier—W. S. Whitney. 616,997
 Air Moistener—W. H. Prinz. 618,615
 Air Compressor—Lowell & Brown. 618,959
 Air Brake—R. E. Wynn. 619,381
 Air Heater—J. Higginbottom. 619,483
 Air, Gas Engine—Eisenhuth. 620,554
 Air Brake—Ansley & Topham. 621,779
 Liquefying Air—Ostergren & Burger. 621,536
 Liquefying Gas—Ostergren & Burger. 621,537
 Air Compressor—H. E. Anderson. 620,822
 Aerating Water in Bottles—H. V. R. Reed. 620,963
 Air Valve—J. H. K. McCollum. 621,841
 Air-Supplying Apparatus—F. A. Baynes. 620,830
 Air Brake Safety Attachment—A. C. Rumble. 624,103
 Air Compressor—F. W. Ensign. 624,002
 Pneumatic Despatch—E. A. Fordyce. 624,201
 Pneumatic Carrier—E. A. Fordyce. 624,202
 Pneumatic Despatch—B. C. Batcheller. 623,970
 Pneumatic Despatch—B. C. Batcheller. 623,971
 Carrier—B. C. Batcheller. 623,972
 Carrier Receiver—B. C. Batcheller. 623,973

- Pneumatic Transmission—Batch-
 eller.....623,968
 Pneumatic Transmission—Batch-
 eller.....623,969
 Air Compressor—A. Roesch.....624,009
 Hydraulic Air Compressor—J.
 Liming.....624,830
 Gas Engine—W. H. & J. Butter-
 worth.....624,750
 Compound Air Compressor—
 Wallick.....624,998
 Valve for Air Motors—J. Craig,
 Jr.....625,324
 Reducing Valve—J. Craig, Jr.....625,325
 Liquefying Gases—J. E. John-
 son.....627,696
 Air Compressor and Cooler—R.
 Berg.....626,883
 Pneumatic Dispatch Carrier—
 Fordyce.....627,181
 Pneumatic Organ—M. Clark.....626,320
 Compression Controller—F. G.
 Hobart.....627,850
 Air Cooler—J. McCreery.....626,390
 Atomizer—R. Morrill.....628,251
 Pneumatic Carpet-Sweeper—
 Westman.....628,505
 Water Elevator—F. Hayes.....628,318
 Air-Brake Hose Coupling—J.
 Caldwell.....629,657
 Air Brake—E. Bartholomew.....629,708
 Triple Valve for Air Brakes—W.
 B. Mann.....630,379
 Engine for Air Pumps—W. B.
 Mann.....630,380
 Air Brakes—W. B. Mann.....630,381
 Air Compressor—R. L. Dunn.....630,495
 Air Compressor—C. O. Sobinski.....630,525
 Pneumatic Propulsion—Walker.....630,821
 Air Controller—S. H. Short.....630,938
 Air Cooler—J. McCreery.....631,377
 Pneumatic Hammer—C. K. Pick-
 les.....631,435
 Air Compressor—C. F. Du Bois.....631,701
 Compressed Air Pump—T. C.
 Wristen.....631,732
 Air Purifier—Fowler & Harpole.....631,868
 Air Compressor—P. H. Montague.....631,994
 Air Drill—A. P. Schmucker.....633,661
 Pneumatic Organ—M. Clark.....632,698
 Pneumatic Despatch—Batcheller.....632,690
 Pneumatic Signal for Trains—C.
 Guiland.....632,813
 Track-Sanding Device—J. H.
 Handon.....633,193
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 Handon.....633,194
 Valve for Pneumatic Tools—J.
 Boyer.....633,355
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 Aylward.....632,207
 Combustion Motor—R. Mewes.....633,878
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 Schmelzeis.....633,735
 Pneumatic Insole—A. Korwan.....632,529
 Pneumatic Carpet Renovator—
 Thurman.....634,042
 Air Feeder for Furnaces—J. How-
 den.....634,348
 Air Compressor—P. Brotherhood.....634,389
 Air Brake—C. N. Dutton.....634,723
 Air Compressor—S. Broichgans.....635,419
 Pneumatic Despatch—Fordyce.....635,434
 Hydraulic Air Pump—Haber-
 mann.....635,478
 Air Compressor—J. P. Simmons.....635,516
 Air Compressor—J. P. Simmons.....635,517
 Air Valve—W. J. Cole.....635,661
 Portable Air Pump—A. B. Diss.....635,674
 Automatic Air Brake—Clarke.....635,695
 Air Compressor—G. W. Tolle.....636,013
 Air Heater—Waterman & Mori-
 son.....636,090
 Air Purifying Apparatus—E.
 Gates.....636,256
 Sand Blast—J. M. Newhouse.....636,279
 Tire Inflator—J. F. Wilson.....636,308
 Pneumatic Valve—H. Leineweber.....636,343
 Cotton-seed Conveyor—J. T.
 Moore.....636,414
 Cow-Milker—N. H. Norby.....636,446
 Compressor, Ice Machines—
 Sharpneck.....636,459
 Sand-Blast Machine—G. S. Slo-
 cum.....636,460
 Air Compressor—S. A. Donnelly.....636,643
 Air Purifier—J. C. Fleming.....636,651
 Cotton-Handler—D. C. Jones.....636,670
 Time Valve—F. L. Dodgson.....636,770
 Air-Brake Hose-Coupling—Park-
 inson.....637,021
 Pneumatic Rocker—Anderson &
 Anderson.....637,065
 Hydraulic Air Compressor—L. E.
 Mitchell.....637,144
 Pump for Compressing Air or
 Gas—H. E. Ludwig.....637,516
 Air Compression—Pettee & Mc-
 Cutchan.....637,659
 Air Motor—Pettee & McCutchan.....637,660
 Air Compression—Pettee & Mc-
 Cutchan.....637,661
 Air Supplier for Diving—F. A.
 Hensley.....638,392
 Pneumatic Despatch—C. F. Bo-
 dinus.....638,409
 Air Compressor—J. H. Hopps.....638,460
 Pneumatic Ram—A. L. Hum-
 phrey.....638,928
 Air Pyrometer—Uehling & Stein-
 bart.....639,317
 Mercurial Air Pump—H. S. Max-
 im.....639,593

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- Air Propeller—A. Duffner, Jr.....640,184
 Air Drier—A. T. Perkins.....640,318
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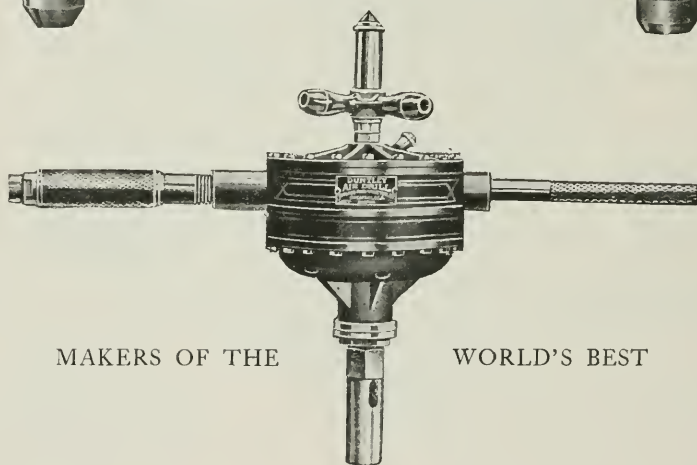
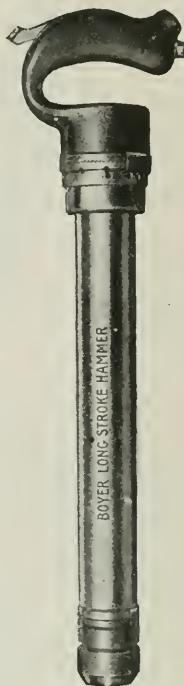
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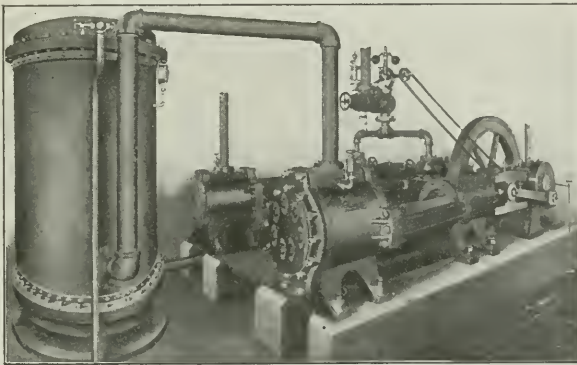
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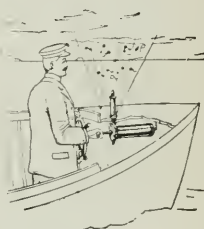
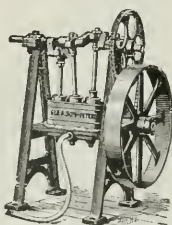
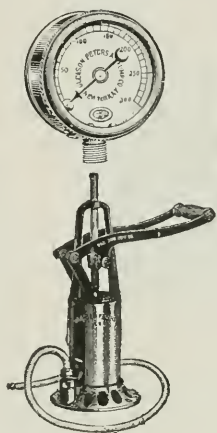
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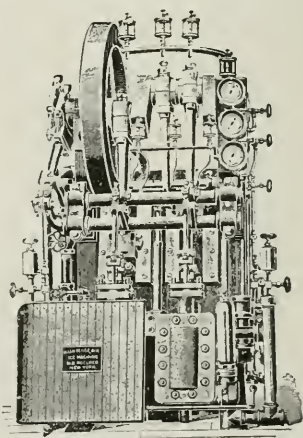
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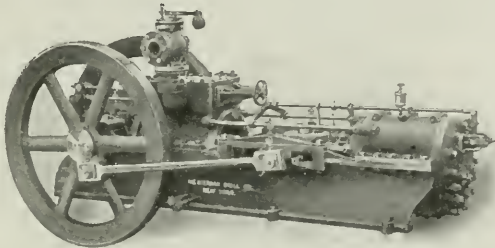
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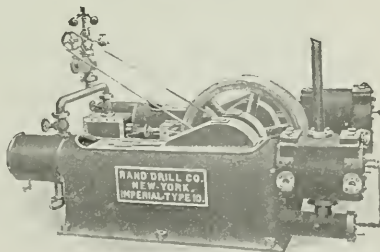
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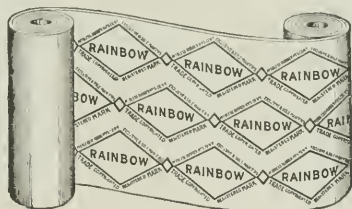
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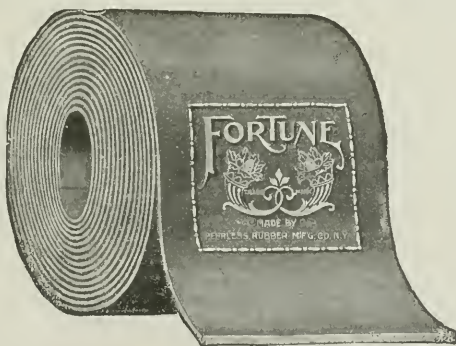
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